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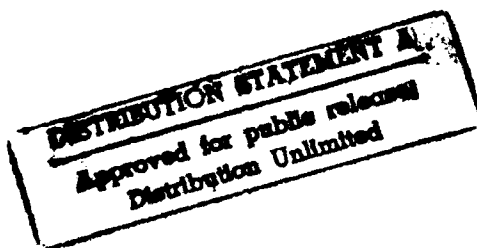Atlantic City International Airport
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# Controller Evaluation of Initial Terminal Data Link ATC Services: Mini Study 3
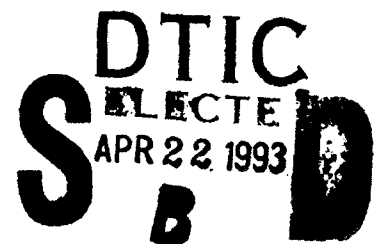
Ground Data Link Development Team

December 1992

Final Report

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**16. Abstract**

This report documents the third Federal Aviation Administration (FAA) controller evaluation of an initial group of four terminal air traffic control (ATC) services and functions which are under development for implementation on a Data Link air-ground communications system. The research was conducted at the Federal Aviation Administration Technical Center by the Research Directorate for Aviation Technology, Airborne Collision Avoidance and Data Systems Branch, ACD-320.

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# EXECUTIVE SUMMARY

## INTRODUCTION.

The Federal Aviation Administration (FAA) is pursuing an initiative to develop and implement a Data Link system to supplement and enhance communications between ground-based air traffic control (ATC) and airborne systems. For the past 4 years, the FAA Technical Center has supported this initiative through a program of research aimed at designing and evaluating initial ATC services and functions for both en route and terminal ATC environments. This report presents the results of the third design development (mini) study conducted to refine and test four terminal Data Link ATC services and functions.

## OBJECTIVES.

The primary objective of the study was to evaluate the usability and operational suitability of designs for initial terminal Data Link services as modified by the results of a prior study conducted in 1991. In addition, the study was used to examine controller strategies for optimizing the effectiveness of Data Link communications, and to evaluate a group of system performance measures for use in future operational evaluation testing.

These objectives were pursued in a series of training exercises and test sessions conducted under high fidelity simulation conditions at the Automated Radar Terminal System (ARTS) IIIA workstations in the Data Link Test Bed. Six ATC specialists from the Air Traffic Data Link Validation Team (ATDLVT) participated in the simulation trials and subsequent debriefing sessions.

## PRIMARY RESULTS.

The design evaluation confirmed the acceptability and utility of the modifications introduced for this study. These modifications included several human factors design features intended to enhance the usability of the menu-based Menu Text (MT) and Terminal Information (TI) services. The results also produced a limited number of additional design enhancements aimed at increasing the adaptability of the menu-based services to varying field requirements.

Simulation testing conducted to investigate strategies for using Data Link in terminal airspace showed that controllers were able to employ Data Link to accomplish nearly all communications tasks. However, Data Link was not judged suitable for time-critical communications used to turn aircraft onto final approach, deal with missed approaches, or resolve aircraft conflicts. Tests in which two-controller teams staffed a combined arrival/final approach sector indicated that, unlike the single channel voice radio

system, a combined voice and Data Link system could be used to reduce aircraft delays under some operations conditions.

Several of the performance measures evaluated during the study showed promise for application to future Data Link testing. In a majority of cases, it was determined that the use of automatically collected measures of system safety, capacity, and efficiency would require close coordination with controller strategies and simulation test scenarios as well as supplementary expert analyses to insure their validity.

RECOMMENDATIONS.

The results of the study support the following key recommendations regarding future terminal ATC Data Link development and testing activities:

1. The results of the design evaluation indicated that the initial terminal services have reached an advanced level of development. It is, therefore, recommended that these services be subjected to operational evaluation in the Data Link Test Bed. This evaluation should involve validation of the service designs through extensive testing by a group of ATC specialists who have not participated in the design development process.

2. In addition to operation evaluation, research should be conducted to investigate unresolved human factors issues which have emerged from the present and other terminal Data Link studies. The most important of these issues are: (a) the comparative potential for undetected communications errors in voice messages and Data Link messages, (b) the significance and performance impact of reports that short-term memory for manually entered Data Link messages may be poorer than that for voiced messages, and (c) the impact on situation awareness of increased "heads down" time for the Data Link controller.

# 1.  INTRODUCTION.

## 1.1  PURPOSE.

This document presents the results of a Federal Aviation Administration (FAA) Technical Center investigation of terminal air traffic control (ATC) services developed for transmission using Data Link technology.  Based on the results of two prior studies conducted in 1990 and 1991, designs for four ATC services were modified and implemented in the currently operational National Airspace System (NAS) Automated Radar Terminal System (ARTS) IIIA computer and ATC workstation for review and evaluation by air traffic controllers.

The controllers participated in simulated terminal airspace test trials to assess the utility of the Data Link services, recommend requirements for additional service design changes, and to examine alternative strategies for maximizing the effectiveness of Data Link communications.  This study was the third in a planned series of iterative design development tests which will culminate in a full-scale operational evaluation and the production of functional design specifications for an operational terminal ATC Data Link communications system.

## 1.2  BACKGROUND.

### 1.2.1  ATC Communications and Data Link.

In response to the phenomenal growth of air traffic in the United States, the FAA has begun to develop and implement a broad range of initiatives aimed at updating and enhancing ATC technology. Many of these efforts are focused on improving the quality and quantity of information that will be needed to increase safety and productivity, and on insuring that this information is reliably and accurately transferred among the computers and humans that form the major components of the ATC system.

One of the primary information transfer problems that constrains the capacity of the current ATC system is the inherently limited communication channel that exists between the air traffic controller and the aircraft pilot.  Because this voice radio link operates in a broadcast mode between a single controller and all aircraft operating in the airspace under his control, frequency congestion is a common occurrence when the volume and complexity of air traffic increases.  Such saturation of the communications channel affects the performance of the ATC system by preventing the timely issuance of clearances and by restricting the vital exchange of information upon which safe and efficient operation of the NAS depend.

In addition to the limitations that it imposes through frequency congestion, the voice radio channel has been identified as a major

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contributor to errors in the ATC system. The FAA has noted that as many as 23 percent of all operational errors are caused either directly or indirectly by communications mistakes (New York Times, 1988). Similarly, compilations of voluntary reports provided to the Aviation Safety Reporting System by pilots and controllers have shown that a majority of all potentially hazardous incidents that are filed implicate ineffective verbal information transfer (Billings and Reynard, 1981).

Investigations of the nature of prevalent communications errors demonstrate that they are typically the result of an interaction between the characteristics of the voice radio system and the inherent perceptual and cognitive characteristics of its human users (Shingledecker, 1990). Acoustic confusions, alphanumeric transpositions, misinterpretation due to pronunciation and phraseology problems, poor memory for transient speech presentations of ATC information, and blocking of the radio channel caused by improper keying techniques are common sources of human-induced error found by these studies. In addition, many errors seem to be potentiated by the frequency congestion problem as users experience difficulty in monitoring for relevant messages on the crowded radio channel, and become reluctant to clarify suspected confusions in order to avoid further congestion.

Data Link is a digital communications technology which is being developed as a supplement to traditional voice radio for ATC communications. As shown in figure 1, Data Link communications can be supported by several transmission media. These include very high frequency (VHF) radio, satellite links, and the Mode Select (Mode S) secondary surveillance radar system currently proposed by the FAA for ATC Data Link communications. These multiple links will be integrated within a common Aeronautical Telecommunications Network to provide seamless air-ground communications throughout the NAS.

Regardless of the specific method used to create the channel, Data Link communications are distinguished from traditional voice radio links in two essential ways. First, unlike analogue voice messages, Data Link messages consist of digitally coded information. Thus, data may be entered for transmission either manually, or by direct access to information contained in airborne or ground-based computers. Furthermore, the capability of a digital system to provide automatic error checking of sent and received messages makes Data Link a highly reliable system which is not susceptible to degradation by interfering noise sources.

The second way in which Data Link differs from the voice radio channel is its capability to discretely address individual receivers. Unlike the simplex radio system which permits only a single speaker to transmit on the broadcast frequency at any point in time, Data Link messages can be sent selectively, and transmission rates are not artificially bounded by the effective

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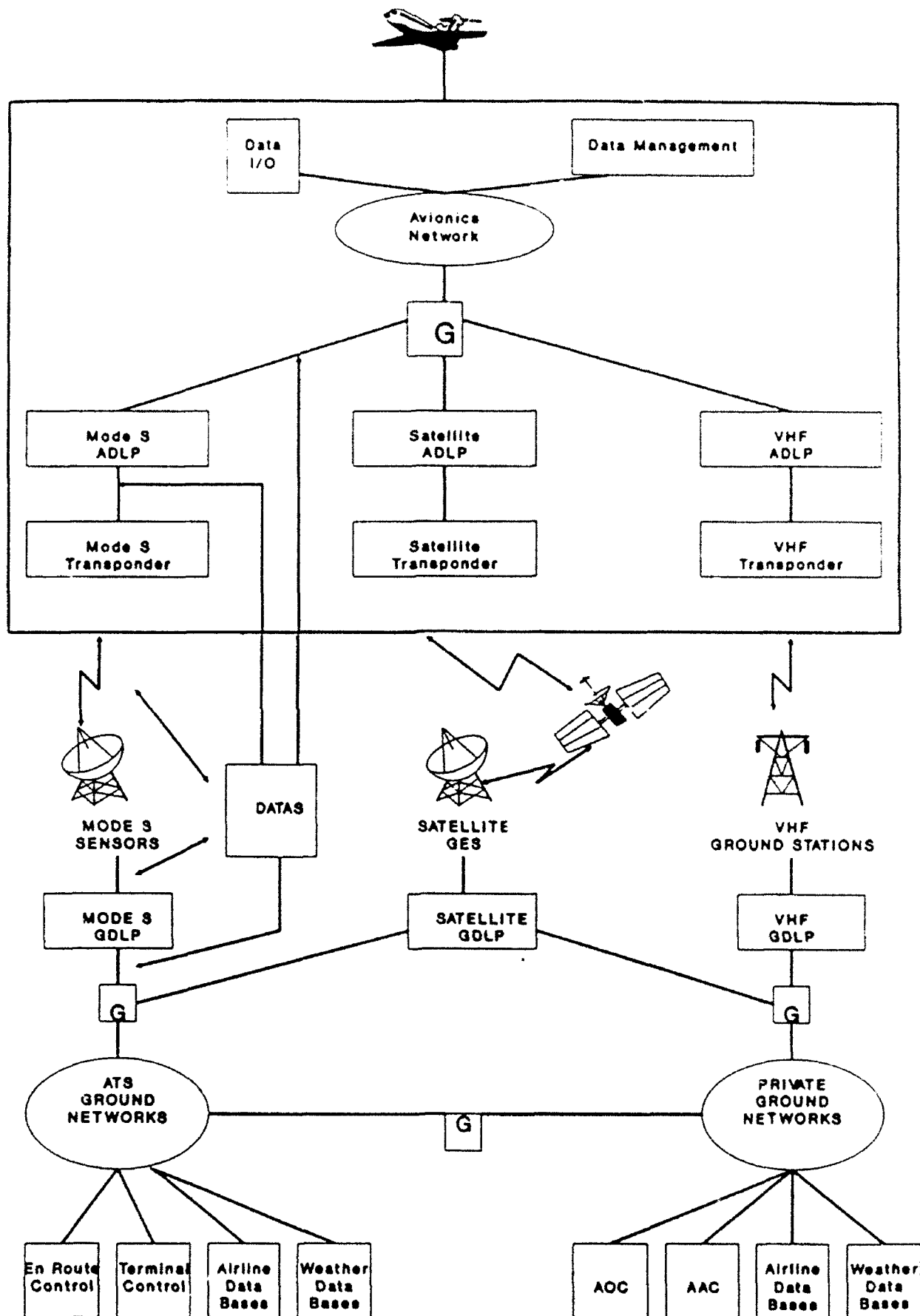
FIGURE 1. PROPOSED DATA LINK SYSTEM

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speaking and listening rates of the user. As a result, Data Link channels can have a much higher capacity than voice channels and critical messages sent by a controller are assured of receipt only by the intended aircraft.

These features of Data Link offer significant promise for alleviating both frequency congestion and errors that currently impair air-ground ATC communications. As more aircraft are equipped with Data Link, demands on the voice channel should be relieved in proportion to the number of weather and ATC services that are assigned to the Data Link system. In addition, by automating or simplifying pilot and controller functions in the communication process that are subject to error, Data Link should improve the overall effectiveness of information transfer. For example, using Data Link it will be possible to reduce ambiguous message transmissions by storing standard clearances in computer memory for simplified uplink to an aircraft; failures to detect messages and accidental acceptance of clearances by unintended aircraft will be eliminated by discrete addressing; interpretation errors should be reduced by the availability of a persistent and recallable visual display of the received data; and the system will automatically verify the integrity of a message without human intervention.

1.2.2 Data Link Research and Development at the FAA Technical Center.

As noted above, the technical characteristics of Data Link have the capability to significantly enhance the safety and productivity of the ATC system. However, Data Link will also introduce a profound change in the way in which ATC tasks are accomplished by controllers, and in the way aircrew will receive and respond to ATC instructions. Because of this, the ultimate success of Data Link will be critically dependent on the extent to which it is employed to create an effective communications system that is thoroughly integrated with its human users and with the full range of tasks that they are required to perform.

Recognition of the need to consider operational suitability and human factors issues as primary drivers of the design process prompted the FAA Technical Center to initiate a program of manned simulation research to guide the development of Data Link ATC services. The overall goals of this research are to (a) define useful Data Link services, (b) determine the user information requirements for Data Link communications, (c) develop display formats, data entry methods and procedures which promote efficient controller performance, and (d) evaluate the impact of Data Link services on both human and system performance.

The Data Link Test Bed was assembled at the FAA Technical Center to address these goals. The test bed is a laboratory facility which uses actual NAS equipment in conjunction with simulation

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computers to create a system capable of realistically exercising Data Link applications in an end-to-end fashion. In its current form, the test bed is composed of the NAS en route and terminal laboratories, the NAS System Simulation Facility (NSSF), and the Data Link laboratory (figure 2). The NAS laboratory includes the HOST computer system used for en route ATC data processing as well as its primary terminal counterpart, the ARTS IIIA system. Both computers are linked to several suites of their respective operational controller workstations which are used to display radar data and to enter system inputs.

The NAS laboratory is linked to the NSSF through the ATC computers. The NSSF permits the NAS laboratory systems to act as functioning control facilities by providing simulated radar data and voice radio inputs from simulation "pilots" operating from computer terminals. Alternatively, the ARTS and HOST portions of the NAS laboratory can be used as self-contained simulation systems using the training functions included within the operational systems. In this configuration, pilot functions are performed by simulation operators working at additional controller workstations.

The Data Link laboratory houses a VAX 11/750 computer which acts as an emulation of the future ground Data Link processor. The VAX computer supports digital communication between simulation pilots and controllers. It can also provide two-way communication between controllers and high-fidelity aircraft simulators or actual airborne systems using Mode S or any other installed Data Link technology.

The central thrust of Data Link research in the test bed is manned simulation research aimed at defining and testing designs for ATC services. This research follows a three-stage approach originally developed and successfully employed under the en route portion of the Data Link program. In the **Design Verification** stage, engineering tests are conducted in the Data Link Test Bed to insure that preliminary designs for Data Link services are faithfully reflected in operational software and hardware components of the test bed simulation laboratories. Following the resolution of engineering issues, a series of manned simulation studies are performed in which air traffic controllers exercise and evaluate the Data Link ATC services.

In the **Mini Study** stage of these experiments, iterative design evaluations are conducted to refine controller procedures, displays, and input requirements. Early studies are completed under controlled, part-task simulation conditions which focus on detailed consideration of basic design issues. As development progresses, simulation exercises are increased in operational fidelity to assess the robustness of the services and to obtain reliable controller judgments of acceptability, usability, and workload effects. A fixed group of Full Performance Level (FPL) controllers from the Air Traffic Data Link Validation Team (ATDLVT)

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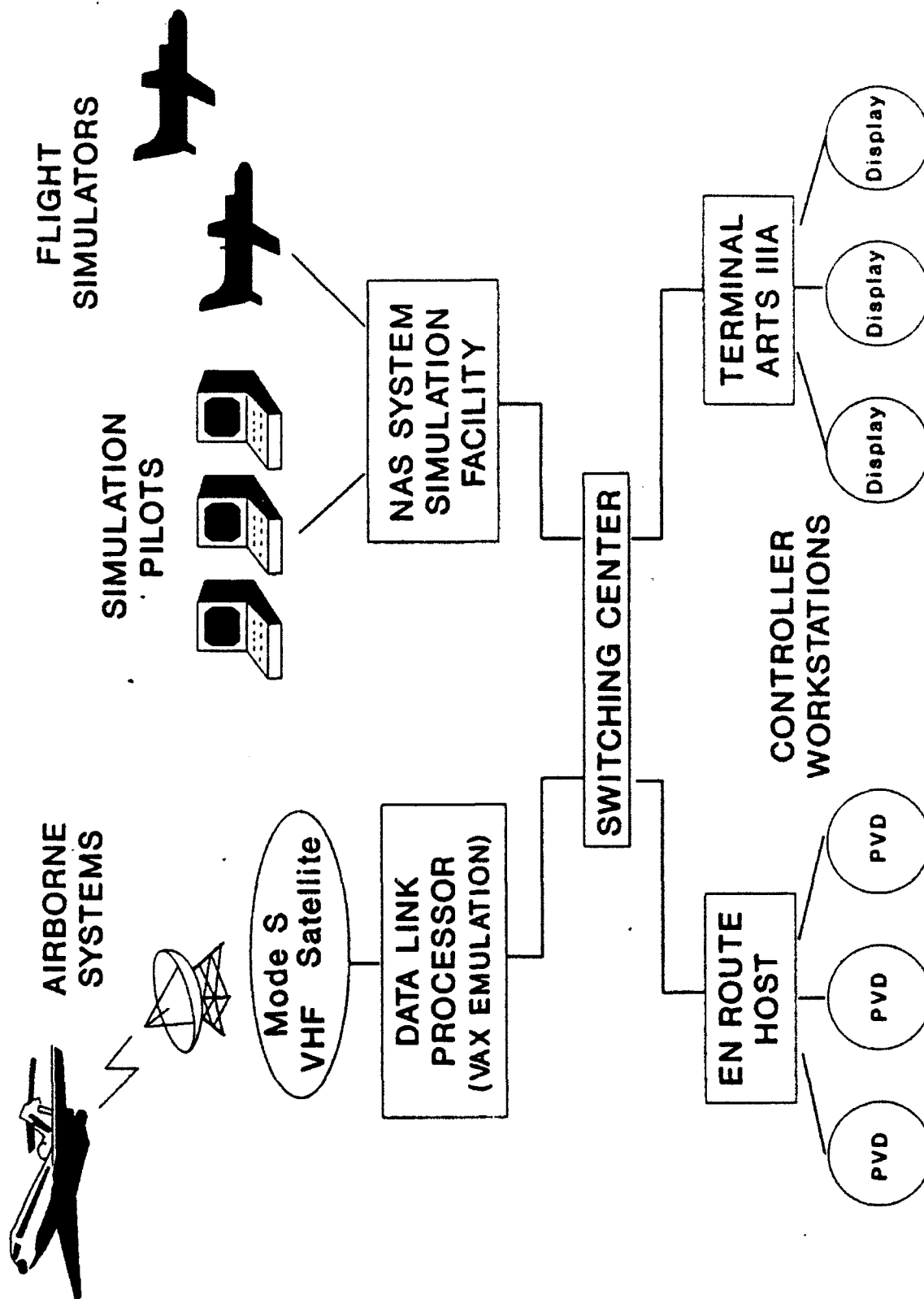
FIGURE 2. THE DATA LINK TEST BED

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participate throughout the mini study stage to provide continuity in the iterative development process.

The final **Operational Evaluation** stage of the approach consists of one or more high fidelity simulation exercises in which the optimized service designs are exercised under a variety of realistic operational conditions and air traffic scenarios. For these studies, a new group of controllers with no prior Data Link experience is recruited for participation. Measures of system effectiveness, controller performance, communications efficiency, and workload are used to verify the utility and usability of the Data Link services. The resulting data determine inputs to a Technical Data Package (TDP) that is used to guide the development of operational Data Link software for implementation in the NAS.

## 1.3  DATA LINK IN THE TERMINAL ENVIRONMENT.

### 1.3.1  Development Issues.

Research and development using the Data Link Test Bed began with the en route portion of the ATC system. Mini studies were conducted to refine the transfer of communication and altitude assignment services as well as a Menu Text (MT) function for uplinking interim altitudes with crossing restrictions, and an unformatted Free Text (FT) function. These efforts culminated in an operational evaluation which demonstrated beneficial effects of the initial en route services on frequency congestion with no observed reduction in controller performance or increase in perceived workload.

The potential value of Data Link communications technology for terminal ATC operations is likely to equal that predicted by the results of the operational evaluation for the en route environment. At present, the demands at busy airports often can result in a terminal controller engaging in prolonged periods of non-stop verbal communication to convey all of the clearances needed to guide the pilots of arriving, departing, and transient aircraft. In addition, the requirement to convey lengthy advisory messages to aircraft entering the terminal area rapidly expends the limited communication time available to tactically control closely spaced aircraft on the approach and departure flightpaths.

While the need to reduce frequency congestion is similar in the terminal and en route environments, the problem of designing an effective Data Link system for the two is quite different. In general, terminal operations are more sensitive to timing issues than en route operations. Because of this, communications functions assigned to Data Link must be carefully selected, designed, and tested to ensure that transmission delays or display clutter do not interfere with controller performance requirements. In addition, unlike some en route clearances, current terminal procedures do not require the use of keyboard inputs to update an

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ATC computer data base. This precludes the use of simple keystroke additions to data base update inputs as a means to efficiently create and send terminal ATC messages. Consequently, particular attention must be directed toward the design of data entries which minimize the workload of entering and uplinking control messages. Finally, the tactical nature of ATC operations in terminal airspace demands that every effort be made to ensure that Data Link displays, inputs, and procedures are sufficiently flexible to permit adaptation to a wide range of operational situations and conditions.

## 1.3.2 Initial Terminal Services.

Drawing from their experience as terminal controllers and an awareness of the design issues outlined above, the terminal subgroup of the ATDLVT met with FAA engineers and supporting contractors in a series of meetings held in 1989 and 1990 to define an initial group of ATC services suitable for the terminal environment. The following services were identified during these meetings:

a. Transfer of Communication (TC). TC is the message sent to an aircraft after track control has been passed to a new sector which instructs the pilot to change radio frequencies in order to communicate with the new controller. Using the designed Data Link service, this message is automatically prepared by the ATC computer and uplinked either automatically or upon a controller input action.

b. Initial Contact (IC). When an aircraft receives a new radio frequency, current ATC procedures require the pilot to contact the new controller and to report the aircraft's assigned altitude and the current Automatic Terminal Information Service (ATIS) code. With the Data Link version of IC tested during this study, the aircraft's assigned altitude is downlinked with the "WILCO" response to the preceding TC. This IC report is passed to the receiving sector through the ground communications system, and is presented to the controller on the radar display.

c. Terminal Information Service (TI). When arriving aircraft enter a terminal airspace, they are typically given a report of the terminal operating conditions and of the approach clearance that they can expect to receive. Using Data Link, these commonly lengthy messages are stored in a menu and sent by a single manual input which initiates the uplink.

d. Control Instructions. This group of services, provided by the Data Link function MT, permits the controller to uplink altitude, heading, and speed clearances. As tested in the present study, these messages could be selected from a predefined menu or composed in real-time using shorthand keyboard inputs.

## 1.3.3 Previous Design Development Studies.

Development of the initial terminal Data Link services began with a demonstration of preliminary designs using a rapid prototyping system at The MITRE Corporation. In 1990, the services were implemented in the ARTS IIIA computer and integrated with the Data Link Test Bed. The first mini design study of these services at the FAA Technical Center was conducted in late 1990 to establish a developmental baseline (Data Link Development Team, 1991).

A second study was completed in 1991 to evaluate versions of the initial services which had been modified on the basis of recommendations obtained from the ATDLVT participants during the first study (Talotta, et al., 1992). The second Mini Study also examined the effects of Data Link transaction times on the utility of the terminal services. Results obtained from the design review suggested that additional improvements in the effectiveness of the tested Data Link services could be achieved by introducing design modifications to increase the usability and flexibility of the menu-based services, the history list, the TC service, and the IC function.

The study described in this document was conducted, in part, to evaluate the effectiveness of the alterations made to the Data Link service designs as a result of these findings.

## 1.4 ORGANIZATION OF THE REPORT.

The following sections of this report present the research methodology that was used and the findings that were obtained in the third FAA Technical Center controller evaluation study of Data Link terminal ATC services. Section 2 describes the specific objectives of the study and the testing approach that was used to achieve these objectives. Section 3 presents the detailed results of the testing. Finally, sections 4 and 5 list the conclusions that were derived from the results and offer recommendations for future efforts toward the development of an operational terminal Data Link system.

## 2. TEST DESCRIPTION.

## 2.1 OBJECTIVES.

This study was conducted to meet the following major objectives:

    a. Evaluate the acceptability of enhanced designs for the initial Data Link terminal services.

As noted above, the results of the second terminal Mini Study included recommendations for changes to the ATC service designs as implemented on the ARTS IIIA equipment in the Data Link Test Bed. Controllers participating in this third study evaluated the

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modified displays and procedures to determine the adequacy and acceptability of the enhanced service designs. The modifications examined during the study included:

1. Addition of shorthand message content data to the status list and data block transaction status displays.

2. Reduction in the length of the history list and relocation to the status list position.

3. Redesign of the IC service to eliminate the altitude request transaction.

4. Use of different message identifier labels in the TI and MT lists.

5. Addition of the ability to independently reposition and suppress the TI and MT lists.

6. Addition of the ability to suppress individual items in the TI and MT lists to reduce display clutter.

7. Relocation of the automatic/hold mode display for TC, and addition of the ability to initiate a sector handoff while a transaction is in progress.

8. Multiple modifications to the MT service to simplify item selection and increase the applicability of individual menu items through automation.

The evaluation also addressed several general design and procedural issues which had been revealed during the prior study. These included:

1. Definition of allowable content of messages included in the TI list.

2. Requirements for unstructured messages in the MT list.

3. Input error potential when entering messages for uplink.

4. Appropriate procedures following message transmission failures and message delete entries.

b. Examine controller strategies for optimizing the effectiveness of Data Link communications.

Beyond the consideration of basic design problems, the present study also was used to provide an initial exploration of communications procedures and approaches that could be used to enhance Data Link effectiveness. Prior research with both en route

and terminal controllers has suggested that optimal application of Data Link may require modifications to current ATC procedures in which only a single channel of communication is available. In order to more thoroughly explore and document potential Data Link communications strategies, test subjects in this study participated in full scale simulation exercises in which current voice radio procedures were compared to combined voice and Data Link communications. For these test runs, the arrival and final approach sectors used in heavy traffic simulation scenarios were combined at single control positions. The subjects operated these positions either as single controllers or as two controller teams.

The purpose of these manipulations was to provide the controllers with an ATC situation in which they could explore and compare alternative strategies of communication in the voice-only and voice and Data Link conditions. The subjects' strategies and evaluations of their effectiveness were documented using questionnaires completed after each test run, individual interviews, post-test comparative ratings, and group discussions.

     c. Evaluate the utility and validity of a group of experimental system and controller performance measures for use in future operational evaluation studies.

The final objective of this study was to evaluate a set of performance measures for use in future operational evaluation research. These quantitative measures will be required for this research in order to supplement expert controller opinions with objective indicators of Data Link's impact on ATC communications efficiency and on overall ATC system performance. The experimental performance measures were collected automatically by the simulation computers during full scale test runs and evaluated for sensitivity and applicability to Data Link operational evaluation research questions.

## 2.2 APPROACH.

The approach that was adopted to meet the objectives of this study involved the participation of terminal air traffic controllers in a series of training exercises, test sessions, and structured debriefings. The simulation test trials were conducted at the ARTS IIIA workstations in the Data Link Test Bed. During testing, subjects controlled traffic in a group of ATC scenarios involving aircraft arrivals and departures at the Raleigh/Durham (RDU) Airport.

Early test sessions were devoted to a detailed review of each of the four Data Link service designs as modified by the results of the second Mini Study. Individual reviews were supplemented by debriefings aimed at achieving group consensus and documenting unresolved design and procedural issues.

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Later sessions were used to compare voice radio air-ground communications to a system supplemented by Data Link under full scale simulation conditions. Air traffic loads were increased from moderate to high levels over the course of each test session. In half of the voice sessions and half of the Data Link sessions, the test subjects worked in two controller teams. The division of duties in these sessions was determined by the team members.

During full scale simulation, voice radio and Data Link usage, as well as a number of experimental performance measures, were recorded automatically by the simulation system. Following each run, the controllers completed questionnaires intended to document their communication and control strategies. Post-test scales were used to obtain controller projections of the impact of team size and Data Link on workload, system capacity, and safety. Finally, individual subject interviews and group discussions were conducted to further document controller strategy differences between voice-only and voice plus Data Link communication conditions.

The general rationale underlying the test design was to provide an ATC environment which could be used by the controllers to assess the capabilities and robustness of the service designs against relatively realistic operational conditions, and to explore the effectiveness of Data Link under various individual and team communication strategies.

## 2.3  TEST CONDUCT.

### 2.3.1  Subjects.

The subjects for this study were eight FPL ATC specialists with current terminal radar control experience. All subjects were drawn from the membership of the ATDLVT. Six of the subjects had participated during the conceptual development of the initial Data Link terminal ATC services and had acted as test subjects in prior mini studies.

### 2.3.2  Test Scenarios and Data Link Operations.

The ATC scenarios developed for this study utilized the RDU terminal airspace. The airspace, local ATC procedures, and test scenarios used during training and testing are presented in detail in appendix A of this report and are briefly described below.

Traffic patterns and procedures used in the scenarios were identical to those used at the operational facility. The single exceptior was that simultaneous approaches to the parallel runways were permitted in the simulation, whereas staggered approaches are required at RDU. Incoming aircraft were routed through two arrival sectors located to the east and west of the airport. During the design review scenarios, each arrival controller accepted aircraft handed off from the Washington Air Route Traffic

Control Center (ARTCC) over two fixes. Overflight aircraft were given clearances for their destination airports, while RDU arrivals were established on a downwind leg or on headings for final approach before control was transferred to the associated final approach sector. Each final controller merged the two streams of aircraft received from his arrival sector and issued the approach clearances. Controllers in the two departure sectors (north and south departure) each directed aircraft to one of two departure fixes according to their flight plans. In both sectors, one of the departure streams crossed an arrival route. This required the controllers to insure that the departing aircraft met specific altitude restrictions while crossing the arrival route.

During the full scale simulation runs, the six sectors were reduced to four by combining the arrival and final approach sectors on each side of the airport. In half of the test runs, each of these combined sectors was staffed by a single controller, while in the other half they were staffed by a two controller team.

The mix of aircraft types used in all scenarios was derived from records for RDU contained in the Official Airline Guide (OAG). General aviation traffic not shown in the OAG was added to the scenarios to enhance realism. All scenarios used during full scale simulation testing presented traffic loads which increased over the course of a run from the equivalent of 75 percent to 145 percent of the RDU arrival acceptance rate. The scenarios differed from one another only in the sequence and spacing of arrivals and departures. Traffic sequences were controlled so that aircraft type or speed when crossing the outer fixes would not introduce confounding differences between the complexity of the test scenarios. Reduced traffic levels were used during training and during the design review phase of testing.

Pilot functions for this study were provided by the NSSF. Pseudo-pilots received voice and Data Link messages from the controllers and made inputs on specialized computer terminals to control the simulated aircraft radar tracks. When responding to voice radio instructions, the pseudo-pilots acknowledged clearances in the normal fashion with a voice response to the controller. Precise control of the elapsed time between the issuance of a Data Link message and receipt of a confirming response was achieved by using the VAX computer to automatically generate and send the pilot acknowledgement to the controller via Data Link. In order to produce realistic temporal coordination between aircraft maneuvering responses and downlinked pilot responses, the VAX computer was programmed to withhold displaying messages to the pseudo-pilots until approximately 8 seconds before the acknowledgement was sent to the controller.

## 2.3.3 Test Procedures.

This study was conducted over a 6-day period.  The first day was devoted to subject prebriefings and training. Data collection began on the second day with individual subject reviews of the Data Link terminal service designs and a debriefing session.  The third and fourth days  and half of the fifth day were used to train the controllers on the combined arrival/final configuration and to complete 12 full scale simulation tests under voice-only and Data Link conditions.  The last half of the fifth day was reserved for strategy interviews with the individual subjects and structured discussion.  On the final day, the subjects participated in a group debriefing covering the service designs and Data Link procedures.

### 2.3.3.1 Airspace and Data Link Training.

To simplify airspace familiarization, the eight subjects were divided into two groups and assigned to either the north or south halves of the airspace.  The subgroups of four controllers were required to learn the arrival, final, and departure sectors only for their assigned half of the airspace.  These assignments were maintained throughout the experiment.

Classroom training time requirements were minimized by providing each subject with a study booklet of materials approximately 2 weeks prior to the study.  This booklet included the RDU airspace procedures and maps, as well as detailed descriptions of the Data Link service inputs and displays.  When the subjects arrived at the test site on the first day, they received a 1-hour review of the airspace and Data Link procedures.  After all questions had been answered, the subjects were taken to the Data Link Test Bed for 2 hours of simulator practice under the normal six sector airspace configuration.

The first hour of practice was used to familiarize the subjects with the RDU airspace and traffic flow.  All communications were conducted using voice procedures.  The second hour of training was devoted to the displays, manual inputs, and procedures for using the initial terminal Data Link services.  For these practice sessions, 75 percent of the aircraft in the test scenarios were equipped with Data Link in order to provide experience with combined voice and Data Link communications.

### 2.3.3.2 Design Review.

Data collection for this study began with a formal review and verification of the ATC service designs as modified by the results of Mini Study 2.  The subjects completed the 2-1/2 hour design review in the Data Link Test Bed while seated at the ARTS IIIA workstations and controlling aircraft in a simplified version of the six-sector training scenario.  All aircraft in the scenario were Data Link equipped in order to maximize the subjects'

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opportunities to examine the service displays, inputs, and procedures. To permit observation of the failure displays, approximately 5 percent of the attempted uplinks resulted in a failed technical acknowledgement (NAK), 5 percent in a timeout (failure of the pilot to respond to an uplink within 40 seconds), and 5 percent in an unable response from the pilot.

During the design review, the subjects' primary task was to exercise each of the Data Link functions a sufficient number of times to thoroughly evaluate the service designs. Evaluations were made by completing a questionnaire booklet during the simulation runs. The subjects were informed that the object of the simulation activity was to aid them in completing the detailed design review, and that maintaining routine control over the moderate (50 percent of capacity) level of air traffic in the scenario was secondary to this task. The subjects rotated among the sectors to permit each individual the opportunity to examine all services. Test facilitators assigned to each sector were available to assist the subjects or to answer any questions about Data Link operations.

The individual design reviews completed in the test bed were followed by two debriefing sessions. The first of these was held immediately after the test bed activity. In this 2-hour session, subjects met with test personnel to perform an item-by-item review of their responses to the design review questionnaire. A 4-hour session was held on the final day of the study. This debriefing was scheduled to take advantage of the additional experience with the Data Link services that the subjects had gained by participating in the intensive, full scale simulation exercises. The emphasis of the debriefing was to identify and resolve disagreements regarding the fidelity and acceptability of the service designs, and to achieve a consensus regarding recommended changes to the service designs. The results of both debriefings were documented in test personnel notes and in an audio tape record for reference during data analysis.

## 2.3.3.3 Full Scale Simulation.

The second major component of this study was a series of full scale simulation tests in which the subjects controlled aircraft in the RDU adaptation using a modified airspace configuration. For these tests, the arrival and final approach sectors on each side of the airspace were combined to create single control positions. The purpose of the test runs was to (1) examine strategies for employing Data Link in single controller and two controller teams, (2) compare Data Link strategies to those adopted under voice radio communication conditions, and (3) evaluate a group of candidate measures of communication and ATC system performance for use in future operational evaluation tests.

Data collection for the full scale simulation was preceded by 2 hours of practice with the four sector airspace configuration

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(two arrival/final and two departure sectors). Following a 1-hour group discussion of the communication and control strategies attempted during practice, the subjects participated in 12 test runs.

The independent variables that were manipulated during these test runs were the communication condition and the number of active controllers at the combined arrival/final sectors. As shown in table 1, voice radio-only communications trials were alternated with trials in which both voice and Data Link communications were available. For Data Link test runs, 80 percent of the aircraft were equipped with Data Link communications, while the remaining 20 percent could communicate only by voice radio.

During the first six test runs, the combined arrival/final sector was staffed by a single controller. For the last six runs, two controllers acted as a team at each combined sector. As shown in table 1, the four controllers assigned to each half of the airspace rotated through each of four stations during the 12 runs. During a test run, three of the controllers from each side of the airspace were assigned to the combined arrival/final sector. One of these was always designated as the radar controller. During the first six runs, the other two controllers acted as observers. During the last six runs, one of these acted as an assistant to the radar controller and the other acted as an observer. On each run, the fourth subject controlled traffic in the departure sector. The rotation was balanced so that within their assigned airspace, each subject participated as an active controller under both voice and Data Link communication conditions.

The subjects were not given explicit guidance regarding appropriate strategies for controlling traffic in the combined sectors or for dividing their duties when performing on two controller teams. Whether acting as observers or active controllers, all subjects seated at the combined sectors were encouraged to participate in the process of generating and evaluating methods for employing the voice and Data Link communications channels.

For all test runs, traffic loads in the departure sectors were fixed at 100 percent of accepted operations per hour at RDU. In the combined arrival/final sectors, traffic load increased during each 40-minute test run from 75 percent to approximately 145 percent of the RDU arrival acceptance rate. The purpose of this manipulation was to permit an examination of the relationship between control strategies and the ability of the subjects to handle increasing levels of traffic.

The average total time which elapsed between the initiation of an uplink by the controller and the receipt of a pilot acknowledgement was randomly selected from a rectangular distribution with a mean of 17 seconds, and a range of 13 to 21 seconds. These nominal delays were selected based on simulation research in which pilot

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TABLE 1. EXPERIMENTAL DESIGN FOR FULL SCALE SIMULATION

| | Run Order | Test Condition | S1 | S2 | S3 | S4 | N1 | N2 | N3 | N4 |
|---|---|---|---|---|---|---|---|---|---|---|
| D2 | 1 | D - 1 | D | O | C | O | D | O | C | O |
| V1 | 2 | V - 1 | C | O | D | O | C | O | D | O |
| D3 | 3 | D - 1 | O | C | O | D | O | C | O | D |
| V2 | 4 | V - 1 | D | O | C | O | D | O | C | O |
| D1 | 5 | D - 1 | C | O | D | O | C | O | D | O |
| V3 | 6 | V - 1 | O | C | O | D | O | C | O | D |
| D2 | 7 | D - 2 | D | O | C | O | D | O | C | O |
| V3 | 8 | V - 2 | C | D | O | C | C | D | O | C |
| D1 | 9 | D - 2 | C | C | O | D | C | C | O | D |
| V2 | 10 | V - 2 | D | C | C | O | D | C | C | O |
| D3 | 11 | D - 2 | C | D | O | C | C | D | O | C |
| V1 | 12 | V - 2 | C | O | O | D | C | O | O | D |

(Left margin label reading vertically: Scenario)

Key:

Subjects: Sn = South
          Nn = North

Test
Condition: D - 1 = Data Link and Voice - A/F 1 Controller
           D - 2 = Data Link and Voice - A/F 2 Controllers
           D - 1 = Voice Only - A/F 1 Controller
           D - 2 = Voice Only - A/F 2 Controllers

Control Positions:  C = A/F Controller
                    D = Departure Controller
                    O = Observer

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response times to Data Link messages have been recorded, and on engineering estimates of Mode S Data Link transmission times.

## 2.3.4 Data Collection.

### 2.3.4.1 Design Review Materials.

The questionnaire booklet used for the design review was similar to that developed for the first and second terminal mini studies. For the present study, the review booklet was organized in seven sections (see appendix B). The first section addressed general system features and procedures common to all services. The second through sixth sections covered the designs of the transaction status list and data block status displays, the history list, the IC service, the TI service, the TC service, and the MT function used for sending speed, heading, and altitude clearances. The final section considered issues surrounding the general design and structure of the menu-based TI and MT functions.

Questions relevant to each of the first six topics were prefaced by a text description of the operational features relevant to the function or service. Initial questionnaire items verified the fidelity with which the test bed service implementations reflected the design modifications introduced for this study by requiring the subjects to judge the correspondence between the descriptions and their actual test bed experience. Succeeding items assessed the acceptability of the service implementations and associated procedures observed in the test bed, and solicited recommendations for any further design modifications. The seventh topic was addressed by a set of rating scales which were used to evaluate requirements for free text vs. structured list items and the utility of several controller interface features intended to enhance performance when locating and selecting menu items.

### 2.3.4.2 Strategy Assessment Methods.

In addition to group discussions conducted after the practice session and after the study was completed, three formal techniques were used to document the strategies that the subjects adopted when using voice radio and Data Link communications when acting as single controllers and when working in two controller teams. The first of these was a questionnaire administered immediately after each test run during full scale simulation.

In all test conditions, the questionnaire asked the subjects to describe their general strategy for controlling the aircraft in the arrival/final sector, and any modifications that they made as traffic load increased during the test run. In addition, the subjects were instructed to record and describe any aircraft separation violations that had occurred in the combined sector.

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In test conditions where two controllers staffed the sector, the team also was asked to indicate how they had divided their general duties and communications (voice and/or Data Link) during the run. In addition, questionnaires completed after Data Link test runs included items which asked the subjects to describe the types of messages sent by Data Link and any changes they had made to the TI and MT lists for the run. Appendix C contains a sample of the questionnaire used after Data Link test runs with two controllers.

The second method used to capture information on controller strategies was an interview technique employed after all 12 test runs had been completed. The interviews were divided into two parts and were administered to the subjects individually by test personnel who also recorded their responses. The first part of the interview was a series of questions intended to document each subject's summary responses regarding the strategies used in single controller and two controller team conditions when voice-only and Data Link communications were available. Additional interview questions asked the subjects to judge the effectiveness of team and individual strategies under the voice and Data Link conditions, and to describe the communication mode(s) used to send each type of ATC service and message.

The second part of the interview used a "critical incident" technique to more fully explore the strategies used by the controllers during test runs in which Data Link communications were available. For the purpose of this study, a critical incident was defined as a challenging event which required the controller to apply skilled ATC interventions, and in which the controller had a choice to use voice or Data Link to resolve the situation.

The interviewers prompted each controller to recall one or more critical incidents, and then asked them to fully describe each incident, construct timelines of the events that occurred, and identify points on the timelines where decisions to use voice or Data Link were taken. The materials used in both parts of the interview are included in appendix C.

The final method used for strategy assessment was a post-test questionnaire that was developed to quantify each participant's expert opinion on how the number of controllers staffing a sector and the availability of Data Link would affect perceived workload, the capacity of the system, and overall safety. A sample of the rating form used to obtain these judgments is presented in appendix C. For each of the three factors, the respondents made all six comparisons between pairs of the four test conditions:

    1 controller   - Voice
    1 controller   - Voice and Data Link
    2 controllers  - Voice
    2 controllers  - Voice and Data Link

In each comparison, they could rate the two members of the pair as equal on the factor (e.g., workload), or judge either of the two as "somewhat" or "much higher" on that dimension. The resulting data were transformed to using the Analytical Hierarchy Process (AHP) to produce ratio scale values for each test condition.

2.3.4.3  Experimental Performance Measures.

In addition to the strategy assessments, a candidate group of objective performance metrics were collected during the full scale simulation tests in order to determine their feasibility for use in future operational evaluation. These measures included controller use of the communications system and indices of ATC system performance.

Because one of the proposed benefits of an air-ground Data Link is a reduction in voice radio frequency congestion, data were collected during the simulation runs to gauge the use of the voice radio and Data Link by the subject controllers. Radio usage was assessed by automatically detecting the occurrence of all push-to-talk activations and deactivations of the controllers' microphone when speaking to the simulation pilots. Recordings of these events yielded measures of the number of controller initiated voice transmissions during a test run and of the amount of time the radio channel was occupied by controller transmissions. The number of Data Link transactions initiated by the controllers were automatically recorded by the VAX computer which acts as an emulation of the future Data Link Processor and is responsible for handling all digital communications in the Data Link Test Bed.

System performance indices that were collected included measures of the degree of spatial separation among aircraft and of the efficiency with which aircraft were handled by the controllers as they moved through the test airspace.

Separation measures recorded by NSSF computers included the number of times two aircraft came within 1,000 feet vertically or 3 miles horizontally of one another, as well as the amount of time that the aircraft spent within these proximity limits. The computers also recorded two additional separation measures: the Closest Point of Approach (CPA) and the Aircraft Proximity Index (API). The CPA is a non-weighted calculation of the shortest slant range distance between two aircraft within the proximity limits. The API is calculated from an algorithm which compensates for differences in vertical and horizontal separation limits by using a weighted combination of the distances. The API vertical component is weighted approximately 18 times greater than the horizontal component and the resulting score ranges from 0 to 100, with 100 indicating a collision between the aircraft.

Efficiency measures also were collected by the NSSF computer. These included the distance flown by each aircraft within a sector,

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the time spent within a sector, the number of controller initiated path changes, and estimated fuel expenditure. Capacity was examined by a minute-to-minute assessment of the number of aircraft handled by each controller, the spacing between landing aircraft as they crossed the runway threshold, and the rate at which aircraft crossed the runway threshold.

## 3. TEST RESULTS.

### 3.1 TERMINAL DATA LINK SERVICES DESIGN REVIEW.

A primary objective of this study was to evaluate the terminal Data Link service designs as modified by the findings of the second mini design study. The following subsections of this report present the results of this evaluation derived from the individual design review booklets and subsequent group debriefing sessions.

#### 3.1.1 General System Features.

Prior terminal Data Link studies have defined several basic human interface and procedural design features which are common to the use of all initial ATC services. These features include keyboard assignments for special function keys, symbology used for the Data Link equipage/eligibility indicator, and basic procedures governing the conditions under which a Data Link transaction can be initiated by the controller. The results of the present study confirmed the acceptability of these general features and defined additional requirements for the time out function, procedures associated with the use of the transaction delete command, the utility of the resend input option, and the need for a global function to restore suppressed displays.

#### 3.1.1.1 Timeout Status Message.

In the tested design, the third line of the full data block and the status list present a message to the controller if a pilot fails to respond to a delivered message within 40 seconds. In the case of the data block, the "time out" message is a flashing "T".

Earlier versions of the Data Link time out message terminated the transaction, and locked out any response that the pilot may have sent after the expiration of the timer. During the second Mini Study, the participating controllers decided that the timeout message should act only as a cue to the controller, indicating that an extended period of time has elapsed since the message was sent. Because of this, it was recommended that the design be modified to permit the controller to continue to wait for a response, if warranted by the ATC situation.

Seven of the eight subjects in the present study reported that this modification was acceptable. The remaining subject felt that

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controllers would not require a special indicator to signal extended response times.

Because the function of the timer was redefined as a controller alert, the subjects were asked to consider whether requirements for appropriate expiration times should be changed. Of the seven controllers who preferred the time out alert, six indicated that intervals shorter than the nominal 40 seconds tested in this study might be preferred. Subsequent debriefing discussions resulted in a consensus that the design specification should require an ability to adapt the expiration time by facility. In addition, the subjects indicated that, within a facility, it should be possible to vary the timeout interval by service type, with more time-critical classes of messages having shorter alert intervals.

### 3.1.1.2 Transaction Delete Command.

The tested design permits the controller to delete a Data Link transaction that is in progress, a transaction that has received an "unable" response from the pilot, or one that has resulted in a technical transmission failure. The delete action clears the data block and status list displays for the transaction and permits the system to accept the next message to the aircraft.

In order to prevent confusion or misunderstandings that could result when the controller makes this delete input, a standard procedure will be required to insure that the aircrew is aware that the transaction has been closed. The controllers who participated in the design review agreed that an appropriate procedure would be to communicate with the aircraft by voice immediately after any delete action. To deal with deleted messages that may not have been displayed to the aircrew, the verbal message must contain unambiguous phraseology that clearly identifies the specific message to be disregarded. In the situation where a downlinked response is received after the Data Link message is deleted and verbal coordination has been initiated, the subjects recommended that the response be recorded by the system, but not displayed to the controller.

### 3.1.1.3 Message Resend Command.

The third general system design issue considered in this study was the message resend command. This command permits a controller to rapidly resend a message that presumably had failed to reach the aircraft. The command was developed to simplify the task of dealing with a message to which no NAK is received, either because of a failure of the system to send the message, or because of message corruption.

The resend command was addressed in this study because emerging information about the architecture of the communications network that is being developed to manage Data Link functionality indicates

that the resend option may not be required. In the Aeronautical Telecommunications Network (ATN), failure to receive a technical acknowledgement at any of several levels of the system will cause the system to automatically resend the message a parameter number of times. If this is unsuccessful, the connection between the aircraft and the controller will be severed.

In response to this design information, the subject controllers suggested that the resend would not be useful and that a failure to send the information after the automatic retry sequence should cause a unique message be clearly displayed in the aircraft data block to indicate that the connection has been severed (e.g., "LINK FAIL"). In combination with the loss of the Data Link equipage/eligibility symbol, such a display would signal the controller to revert to voice communication with the aircraft or to initiate actions that would reestablish the Data Link connection. The NAK message and the resend option should be retained only if a message transmission failure is possible prior to the point where the message has passed to the ATN, and there is a guarantee that it could not have reached the flight deck.

The fact that several technical acknowledgements will be generated within the ATN also led the controllers to question the meaning of the "delivered" message provided in the status displays. While it was previously assumed that this message would indicate only that a digital check on the integrity of the message had been performed by the initial stage of the airborne receiver, other ATN technical acknowledgements could imply that it was available for display on the flight deck instruments, or that it had been called to the display device. The controllers agreed that, other than a pilot WILCO or UNABLE response, no technical acknowledgement provides assurance that the aircrew has read the message or is considering a response. However, they also felt that for any message status display to be of value, the controller will require clear knowledge of the meaning of the message and of the types of action that they will be able to initiate to bring closure to the transaction in a timely manner. If the status message is ambiguous or if no usable information is provided by the status message, the subject controllers indicated that the message should not be displayed. In general, the subjects felt that end-to-end simulation will be required to determine whether confusions or misinterpretations occur when the "delivered" message means that the message is available for display or when it means that it has been sent to the display device. While all current transaction state displays should be retained in the design specification for the present, an ability to individually suppress these status messages should be included pending the outcome of future simulation research.

### 3.1.1.4 Global Reset of Suppressed Displays.

As the human-computer interface for the terminal Data Link services has evolved, requirements for informational lists and menus have

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increased. In order to minimize the space on the radar display consumed by these features and reduce general clutter, options have been included in the design which permit the controller to suppress and retrieve entire lists or selected components of the displays. The large number of individual retrieval commands unnecessarily complicates the task of resetting the system to a nominal state when changing controllers at a position. Because of this, the subjects in the current study recommended the addition of a global reset input which would retrieve all suppressed displays. Affected displays would include all MT and TI items, the TC mode, and the status list.

### 3.1.2 Status List and Data Block Transaction Displays.

Two changes to the status list and data block displays were introduced for this study. As suggested by the results of the second Mini Study, the message content of a MT clearance was indicated using a shorthand code rather than the item number from the MT list. Thus, for example, rather than displaying "M2" to indicate that message number two had been sent, the shorthand "A120" was displayed to abbreviate the message content (Altitude 12,000 feet). The design retained the use of message identifiers to denote the content of TI messages.

The second modification to the data block display was the use of single letters rather than three-letter abbreviations for the transaction status indicators. These indicators were shortened in the data block in order to provide sufficient space on the third line for the extended message content data described above.

All eight controllers reported that they preferred the shorthand content display over the previous item identifier display. Two controllers indicated that the identifier display should be retained as an option adaptable by the facility. Explanations offered by the subjects regarding their preference for the shorthand display included quicker content reference without consulting memory or the MT list, improved feedback and error detection for the most recent clearance sent, and improved team coordination and communication in sectors using a coordinator or handoff assistant.

All of the controllers also indicated that the use of the item identifier for the TI message content display was acceptable, and that the use of an asterisk in the display helped to signify the message type (e.g., "T*A").

All of the controllers agreed that the single letter status displays in the data block would be acceptable. However, three controllers noted that the "failure" status types (U,N,T) should flash at a different rate to distinguish the event from a handoff and make the event more salient.

In agreement with the results of prior studies, a majority of the controllers indicated that they do not use the status list to monitor Data Link transactions. However, all controllers felt that the persistent 8-second WILCO display would be useful for individuals who choose to employ this display.

### 3.1.3 History List.

Only minor changes were made to the history list for the present study. Based on past results, the list was reduced in length from the last five messages WILCOed by an aircraft to the last three messages. In addition, when called by a keyboard command, the history list appeared in the status list position rather than in the TI and MT list position.

All eight subjects indicated that the three message list provided adequate information regarding the Data Link transaction history of an aircraft. However, during debriefing discussions, the subjects agreed that design specifications should permit site adaptation of up to five messages in order to accommodate unforeseen field requirements. All of the subjects also preferred the status list position for the history list over the MT position. A majority of the controllers felt that the 8-second display time for the history list would be sufficient for a three-message list. However, the subjects also felt that this time parameter should be adaptable by the facility. Additional improvements suggested for this feature included an ability to examine the Data Link history of an aircraft under another sector's control, and requiring the history to carry over across sectors within a facility. Finally, a "clear/enter" keyboard command was recommended as a replacement for the "HL slew" input to cancel the list prior to its automatic removal.

### 3.1.4 IC Service.

The IC service was modified for the present study to eliminate the transaction delay produced by a routine requirement to initiate the service by an altitude request uplink. In the tested design, the IC message was downlinked from the aircraft by appending its assigned altitude to the pilot's WILCO response to the preceding TC. Altitude requests automatically initiated by the system were used to elicit the IC from departing aircraft and from aircraft which failed to append the message to the TC response.

All of the subjects preferred the modified service, and none foresaw operational problems associated with the new procedure.

### 3.1.5 TI Service.

The tested design of the TI service was modified for this study to increase the permissible length of the displayed messages, and provide greater flexibility in positioning the list and controlling

the number of displayed items. All subjects felt that the 40 character line length was acceptable. However, it also was noted that, because of the broad range of content that can appear in a TI message, a standard abbreviation dictionary will be needed for entering these messages and displaying them to the controller. All controllers also preferred the change from numerals to alphabetic characters as item identifiers for the TI messages. This modification was introduced to reduce the occurrence of confusions among TI and MT item selections.

The ability to position and suppress or retrieve the TI list independently of the MT list also was a preferred change. In addition, all controllers felt that the ability to suppress individual list items would reduce display clutter and simplify item selection.

The tested design permitted the combination of a TI message with a MT message in a single uplink. Five of the subjects indicated that the flexibility to combine these two message types should be increased. During debriefing, all subjects agreed that it will be necessary to provide controllers with the ability to combine more than one MT clearance with a TI message. Ideally, it should be possible to send a TI message with as many as three MT messages (altitude, heading, and speed). In addition, the subjects suggested that it should be possible to enter and send the combined TI message and MT clearance in any order, rather than requiring the TI message to precede the MT message.

Other suggested improvements to the TI service were oriented toward simplifying the process of modifying the list. These included the ability to selectively edit numeric values in a message, and a feature which would automatically change the full list to conform to a change in runway configuration.

Finally, one subject suggested that two alternate displays of the TI list items be made available to the controller. One of these would be the abbreviated text version used in the current design. The alternate would be a compressed representation containing only key information from the message.

3.1.6 TC Service.

Modifications to the TC service introduced for this study included a change in the mode display, adding the ability to offer a sector handoff when a Data Link transaction is in progress, and suppressing the receiving sector's display of the status of a TC transaction.

The mode display provides an indication of whether the TC will be automatically sent or held for manual uplink after a sector handoff is accepted. All of the subjects preferred the placement of this display in the System Data Area (SDA) over its former position in

the first line of the status list. However, the controllers also suggested that a command be added to permit suppression of the mode display when not required.

All subjects also expressed satisfaction with the added ability to offer the sector handoff while a transaction is in progress. This feature presents a time savings because it does not force the controller to wait for an ongoing transaction to be WILCOed prior to making the data entries which complete the handoff and automatically prepare the transfer message. An additional improvement discussed during the debriefing and recommended for future testing was the addition of an entry which would further reduce the requirement to monitor ATC clearance and TC messages spaced closely in time. In this proposal, after a sector handoff is accepted and the TC message is available for manual uplink, the controller would have the option to enter a MT clearance followed by an "S". This additional entry would automatically send the TC immediately after the pilot WILCOed the clearance was received.

Mixed responses were received to the suppression of the data block display of a TC being conducted by a sending sector. While six controllers felt the display increased clutter, two subjects indicated that they preferred to monitor the status of the transaction. A compromise accepted by the controllers during the debriefing was to continue to suppress the display of this information, but to add an input (e.g., ok) that would permit the controller to view the history list, status list and data block displays of individual aircraft at other sectors.

3.1.7 MT (Speed, Heading, Altitude Clearances).

The results of Mini Study 2 indicated that, under high workload conditions, controllers experienced some difficulty in using the terminal ATC services which were based on a menu interface. As a consequence, a number of design changes to the MT and TI functions were introduced to enhance the flexibility of the system and to improve the speed and accuracy with which controllers were able to locate and send menu items.

In order to increase the utility of the MT service while maintaining reasonable menu length, individual menu items were redesigned to contain "generic" altitude, heading, and velocity values. When selected for uplink, the direction of an altitude change (climb/descend) or of a velocity change (increase/decrease) was added to the message by system automation. For heading changes, the controller could precede the menu item number entry by "L" or "R" to include the direction of the turn in the uplinked message. Each of these modifications effectively doubled the number of available menu messages without increasing the number of displayed menu items.

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All of the subject controllers favored the generic message structure for the MT items over the earlier design in which each item represented a single clearance.

The following are design features of the MT and, in some cases, the TI service human-computer interface that were introduced for this study with the intent of reducing error and simplifying the task of uplinking messages:

a.  To reduce inadvertent selection of items from the unintended list, letters were used as item identifiers for TI messages and numbers for MT messages.

b.  Headers (HDG, ALT, VEL, MULT) were used between groups of menu items to assist in the task of locating desired messages in the MT list.

c.  Unused menu items could be individually suppressed to reduce list length and display clutter.

d.  The full MT list or TI list could be suppressed to reduce display clutter.

e.  The MT and TI lists could be independently positioned on the radar display to minimize visual scanning requirements.

f.  The key entries used to prefix menu by-pass (manually entered) clearances (H,A,V) were selected because they appear in a single column on the ARTS keyboard and in the same order as they appear in the MT list.

During the design review, the subjects were asked to evaluate the effectiveness of each of these design features on a 7-point scale with a center point of 0 "no effect on errors or performance," and ranging from +3 "very positive effect" to -3 "very negative effect."  Ratings received by each of the design features are presented below:

| Design Feature | Controller Subject No. | | | | | | | | Median Rating |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | |
| a. | 1 | 3 | 3 | 3 | 2 | 2 | 3 | 3 | 3.0 |
| b. | 3 | 3 | 2 | 3 | 1 | 2 | 3 | 2 | 2.5 |
| c. | 1 | 3 | 0 | 3 | 2 | 3 | 3 | 2 | 2.5 |
| d. | 1 | 1 | 2 | 3 | 3 | 2 | 3 | 2 | 2.0 |
| e. | 3 | 3 | 3 | 3 | 3 | 2 | 3 | 1 | 3.0 |
| f. | 3 | 1 | 2 | 3 | 2 | 2 | 3 | 0 | 2.0 |

As shown above, none of the design features added to the menu-oriented TI and MT services received negative effect ratings from any of the subjects.   While the use of differentiated item

identification numbers, and the ability to independently position the two menus (features 1 and 5) received the highest median ratings, a non-parametric analysis of variance indicated that the six features were not significantly different in terms of their overall positive benefits ($Chi^2 = 1.929$, $p=.85$). Inspection of the data suggests that the failure of any subset of features to emerge as more highly beneficial than the others was a result of a high level of intersubject variability. While nearly all subjects predicted some positive performance impact of all features, individual subject's judgments of the magnitude of the benefit ranged from modest to high in every case.

### 3.1.8 Content and Application of the MT and TI Lists.

Over the course of development of the MT and TI services, a variety of modifications have been made to these menu-based services to improve their operational suitability and usability by controllers. As a part of the design review, the subjects were asked to evaluate whether the MT menu provided sufficient flexibility to meet field requirements and to express their opinions regarding the assignment of message types to the TI and MT lists.

As designed for the initial terminal ATC services, the MT list is a completely structured menu. Individual lines are assigned to specific clearance types and the content of each line is highly standardized. This design approach permits extensive use of automation to construct the uplinked message and provides for more efficient coding of the clearance for digital transmission than a free text message. The limitation of the structured menu design is that it may offer insufficient flexibility to represent the full range of clearance messages that the controller may wish to send. During development, the following features were progressively added to the design in order to increase menu flexibility:

   a. Menu items dedicated to speed, heading, and altitude clearances with the ability to change individual numeric values on line.

   b. Capability to combine individual speed, heading, and altitude menu items in a single uplink.

   c. Capability to create a special multiple clearance line in addition to the individual speed, heading, and altitude items.

   d. A menu bypass feature for composing clearances not contained in the menu.

   e. Generic clearance messages with automatic determination of climb/descend and increase/decrease, plus the ability to control turn direction.

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f. Capability to combine a TI and a MT item in a single message.

The controllers were polled to determine whether the existing MT design with these features would be sufficient for generating the clearance messages that will be needed in the operational terminal ATC environment. All eight controllers indicated that the design appeared to be sufficient, and that the use of an unstructured, free text approach to the MT service would not be required. However, in discussions following the full scale simulation phase of the study, the controllers agreed that maximal efficiency of the structured menu would be achieved by removing the current limitations on the number of messages that could be created in each clearance category. That is, within the limits of total menu length (e.g., nine items), it should be possible to have more than one combined clearance line, and as many speed, heading, and altitude lines as required by the control sector.

The issue of differential assignment of messages to the MT and TI lists is one which has been reconsidered several times during the development process. In the original configuration, the TI menu was restricted to the informational messages that are sent to aircraft as they enter some control sectors, while the MT menu was used for all control clearances. As a result of extensive testing during full scale simulation in the second Mini Study, the application of the TI menu was extended to include clearances commonly sent in conjunction with these informational messages, and to other messages not suited to the structured MT list design. Debriefings following that study suggested that this extended application could reduce the functional distinctiveness of the two menu lists and create difficulties in locating and selecting desired items for uplink.

This issue was revisited following the extended simulation trials of the present study. The consensus among the controllers was that the TI menu should not be arbitrarily restricted to purely informational messages. Any benefits of such a restriction were seen as being outweighed by the ability to efficiently combine logically related message elements. In the redefined logic for message assignment, it was agreed that the MT list will continue to be used for structured clearances as described above. The TI menu will contain lengthy, repetitively used, text-oriented messages, including an associated clearance when required. The subjects indicated that these messages will encompass those typically considered to be the first and last messages sent by a terminal controller depending upon the sector entry point of an aircraft or its destination.

### 3.1.9  Input Error Prevention and Situation Awareness.

The final topics considered during design review debriefing were keyboard entry errors and the impact of Data Link entries on the controller's awareness of prior messages sent to an aircraft.

The terminal Data Link initial service designs make exclusive use of keyboard entries to select messages for uplink from menus and to compose messages in a shorthand form. In the current design, potential data entry error was taken into consideration by differentiating item identifiers in the two menu lists. Additionally, shorthand abbreviations of sent messages were added to the status list and data block to enhance self detection of errors.

While quantitative data have not yet been collected to determine actual Data Link input error rates, the subjective response of test controllers indicates that significant error potential may exist when entering clearances using the menu bypass function. The subjects agreed that removing the bypass function from the design to prevent error is an unacceptable solution which would significantly decrease required flexibility in the system. Alternatives that were considered included the use of unique two-letter abbreviations rather than single letters when defining the clearance type, employing different numbers of digits to specify the numeric value for each clearance type, and automatic computer checks on the reasonableness of the clearance entered for uplink.

Because each of these alternatives could adversely impact controller workload or software complexity, it was determined that research should be conducted to determine the actual nature of errors made in both voice messages and Data Link entries, and to assess their comparative rates of occurrence. This research must examine both controller detected and undetected errors in menu selections and by-pass composition. In addition, the research should address any potential for error in calling implied functions elicited by track ball entries and keystrokes which, if entered at inappropriate times, could initiate unintended actions.

Controller memory for messages sent by Data Link also was discussed during the debriefing. Anecdotal accounts of forgetting whether an intended message actually had been sent to an aircraft and of failing to remember the content of a message known to have been sent were discussed during prior mini studies. In the current study this issue was reconsidered, and the subjects agreed that although the history list acts as an aid to memory, failure to remember messages could affect the quality of the controller's situation awareness, or the workload associated with maintaining required situation awareness. It was decided that future research should be conducted to determine whether short term memory for voiced and manually entered ATC messages differs. This research also should examine the hypothesis that bypass messages which

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articulate the intended message may produce better memory than clearances selected from a menu list.

## 3.2 FULL SCALE SIMULATION.

### 3.2.1 Strategy Analysis.

#### 3.2.1.1 Strategy Questionnaires.

The results of the questionnaires distributed between test runs indicated that when controllers worked individually, normal (current) operational procedures were implemented in voice-only runs. When Data Link was available, two controllers initially used all Data Link, but, as traffic load increased, called for an assistant who took on Data Link for TI and IC messages while the primary controller used voice. Other controllers applied the strategy of using all voice on final approaches and Data Link for initial messages.

Controllers varied from using Data Link for TI messages only to using it for TI messages, initial vectors, expected approaches, headings, altitudes, and speeds. Controllers who used Data Link more often reported switching to voice in some cases due to pilot errors. In all cases, Data Link was used much less often for turns onto final approaches. When traffic was heavy, strategies included going to voice for clearances farther out from final, using reduced speeds, and asking an assistant for help.

All controllers reported using the TI list in all cases. All six reported using MT clearances. Five said they bypassed the menu as they got closer to the airport and when busy. The sixth controller said he went to voice under such conditions. It appeared that for some controllers there was a progression from MT to the bypass function to voice as aircraft got closer in and as controllers became busier.

When two controllers worked voice-only as a team, two basic strategies were used. Two teams indicated that the assistant controller performed no function. The remaining four teams said that the assistant took on duties typically handled by a second person assigned to a sector in the field. These included taking sector handoffs, performing this task plus acting as a monitor providing a second pair of eyes, and moving data blocks after the approach clearance was given. None reported sharing the radio. In general, voice-only strategies appeared to be identical in the one and two controller conditions. With two controllers, the second person either acted as a relatively passive observer or took on normal duties of a handoff man.

In the Data Link team situation, all controllers reported extensive use of Data Link. This ranged from using only TI, initial speeds, and headings to using Data Link for all functions. Those who

adopted the second strategy noted that most use of voice was done to compensate for some simulation pilots' inability to deal with large numbers of multi-element Data Link clearances. It should be noted that these problems experienced by the simulation pilots were attributable to message display methods and procedures used in the NSSF rather than to limitations that would be experienced by actual pilots in an operational setting.

Three basic strategies for dividing duties were adopted by the teams. None of the teams reported sharing the radio frequency. In every case, the radar controller used voice while the assistant used Data Link. The strategies differed in the extent to which the primary controller used Data Link in addition to voice, and in the manner in which communications duties were divided between the team members.

Strategy A:     (Two teams) Highly defined duties and control area, Data link not used by primary controller.

   Controller:  Voice-only, handled turns to final and approach clearance, dealt with non-Data Link arriving aircraft on request from assistant.

   Assistant:   Data Link only, used TI and MT list on outer fixes and gave initial headings and altitudes. One team also monitored controller's load on final and used Data Link to reduce speeds.

Strategy B:     (Three teams) Defined duties, extensive use of Data Link by both.

   Controller:  Used Data Link and voice. Gave final turns and approach clearances by Data Link as much as possible, used voice for arrivals on request.

   Assistant:   Used Data Link, handled TI and used MT for clearances, and any others on request.

Strategy C:     (One team) Fully integrated, no set duties, high level of coordination required, both used Data Link.

   Controller:  Shared sequencing decisions and clearances.

   Assistant:   Repositioned data blocks on final, shared sequencing decisions and clearances.

The controllers reported several approaches to dealing with heavy traffic volume. One team indicated that they made no changes to their approach. Two teams reported that as simulation pilots fell behind, using Data Link became more difficult and resulted in an increase in voice usage. Two teams reported sending speed and heading changes earlier, and increasing speed control. Finally,

one team reported that the assistant used combined TI and MT messages to position arriving aircraft more efficiently while the primary controller went to voice.

Several controller teams reported modifications to the TI and MT lists. It appeared they did this more in the individual controller condition to better deal with the traffic. Three teams reported developing a TI message which contained multiple elements including altitudes and approach clearances. This effectively reduced the number of messages sent. One team changed a heading value in TI, another suppressed a message. In MT, two teams made a new multiple clearance and one modified a heading. All teams used MT. Bypass was used extensively by teams in which primary controller used Data Link, especially as traffic increased and when using Data Link for vectors to final.

### 3.2.1.2  Individual Strategy Debriefings.

The results of the initial debriefing questions at the end of the full scale simulation indicated that when working individually, two of the eight controllers reported using Data Link almost exclusively, and noted that they compensated for Data Link delays by sending messages earlier with Data Link. The other controllers reported using voice for critical situations, "fine-tuned" clearances, inner fixes, and finals, whereas they used Data Link on outer fixes and departures. Aircraft were slowed sooner because of Data Link communication delays, and the bypass function and voice were used as traffic increased.

When the controllers were asked to choose which communication condition was more effective when working individually (voice-only or Data Link) four elected voice-only. Their reasons included not having to worry about delays, not being distracted with new working tools, being able to concentrate on traffic and not the keyboard, and being able to make tighter finals. Additional comments about Data Link included unfamiliarity with the menu, heavy workload, and increased workload for tactical commands. Two controllers said that Data Link was the more effective medium when working alone. One controller found neither strategy to be more effective than the other, and one controller's response was unclear.

In the voice-only team conditions, all teams used normal voice procedures. As in the between run interviews, two teams reported that the assistant controller was not used at all; no team work. Two teams reported that the second controller was an additional set of eyes, but was basically ineffective. Three teams reported that the primary controller did all the voice and the second controller only took handoffs. Only one team used the second controller to keep the data blocks straight in addition to taking handoffs. None of the teams reported sharing the radio.

Different strategies were applied when using Data Link as opposed to voice-only when controllers worked in a team. All controllers reported extensive use of Data Link, specifically for TI, altitude assignment, heading changes, and speed changes. All controllers reported they would switch to voice for conflict resolution and to deal with missed approaches, but would switch back to Data Link after a conflict was resolved.

All of the controllers reported sharing duties when using Data Link. In some situations, one controller was basically in command and did most of the work until the workload became heavy, then teamwork was necessary. One controller usually gave clearances and took handoffs, but in some runs, both controllers issued clearances.

When the controllers were asked to choose the more effective team strategy, voice-only or Data Link, six out of eight controllers elected Data Link. They indicated that the second controller made a difference, preliminary instructions could be given, and two modes of communication were very effective. One controller, however, indicated that with Data Link, more simulation pilot errors occurred, and another controller mentioned that although Data Link was very effective, voice was still used on final. Another controller mentioned that more experience was needed with Data Link. The remaining two controllers chose voice-only as the more effective strategy because Data Link required too much coordination between controllers, was less efficient, and did not allow for optimal spacing during finals.

The controllers were also asked to recall a specific critical situation they encountered during the simulation runs and to indicate whether they used Data Link or voice-only to deal with the situation and why. It was found that voice was used more often to communicate with a departing aircraft, for final clearances, and to resolve conflicts because of the instant communication to and the immediate response from the pilot. Data Link was used "when there was time to use it." The controllers on one team reported using Data Link, but only because time was not a critical factor. If time had been a critical factor, they would have resorted to voice. One controller added an additional comment that simulator pilots had a hard time keeping up with traffic, and another controller said the pilot kept up with the controller when Data Link was used, but fell behind when the controller switched to voice.

### 3.2.1.3  Group Discussion of Strategies.

Debriefing sessions were conducted following the test runs. Their purpose was to reexamine the Data Link service designs in light of the subjects' experiences with Data Link. Other discussion topics included global design philosophy issues, strategies for combining voice and Data Link, potential opportunities for controller error

in using Data Link, and the overall projected effects of Data Link on ATC.

Subjects were asked whether they found the individual or team strategy more effective when using the Data Link. The team concept was agreed to be highly effective, since it allowed for both controllers to issue instructions to many aircraft at the same time. If one controller handled voice-only, he could take care of situations needing immediate attention, such as missed approaches, missed turns, missed altitudes, or missed instructions of any sort, while the second controller could issue instructions to other aircraft with Data Link to maintain a safe situation. In voice-only scenarios, the teammate contributed little or nothing. Data Link, on the other hand, was a cooperative effort, usually with one controller considered to be in command.

As one controller commented, when a critical situation arose while he was working individually with Data Link or voice, he caused delays by spinning aircraft on the outer fixes so that he could focus on the immediate situation. With Data Link and a second controller, however, all the initial work was done for him and, thus, the flow of traffic continued to run smoothly. Data Link, in a sense, allowed for two frequencies. When asked whether working with Data Link in busy situations made any difference, one controller explained that the mental picture he formed by constantly scanning the screen was disrupted by having to look down at the keyboard. He reported a loss of concentration with Data Link. Other controllers commented on the unfamiliarity with Data Link.

The general consensus gathered from the debriefing sessions was that with combined sectors, it was easier to handle traffic with Data Link when one person handled voice, and the other person handled Data Link. It was agreed that it is always beneficial to have a second set of eyes. A problem pointed out by one controller, however, was most of the controllers had not worked together before this test and, therefore, were not familiar with each other's habits. The controllers felt that their performances were more efficient the second time they worked together, and the experiment probably did not reflect what could have been done by a crew who worked together on a regular basis.

The effectiveness of Data Link, in general, in the terminal environment was also discussed in the debriefing sessions. One controller commented on Data Link as beneficial in certain special situations, such as with an emergency aircraft requiring continuous instructions or a stuck microphone blocking a voice frequency, but no more effective than voice in normal traffic flow. Another controller considered Data Link to be effective in heavy volume situations, especially on departures, where more aircraft could be controlled.

Most of the controllers interviewed said they would not use Data Link for finals because much more attention must be given to the aircraft that is making the final approach. It was distracting to have to look down at the history list to make sure the message was sent to the Data Link target. One controller reported feeling more pressure working departures using Data Link because it involved too much preliminary thinking about what message to send, as opposed to simply having to speak what was on his mind.

As noted in the design review results, the relationship between short term memory and Data Link was also discussed during the sessions. One controller mentioned that when using Data Link, he would often have to go back to the history list to make sure an instruction had been sent. In one instance he found that he had typed the same message twice with Data Link. Memory for voice instructions, on the other hand, was not a problem. Other controllers agreed that it was usually easier to catch a voice error as opposed to a Data Link keyboard error.

## 3.2.1.4  Discussion of Strategy Results.

The availability of Data Link in addition to voice communications makes possible the development of new strategies for the control of aircraft in the terminal environment. In Mini Study 3, the provision of a team condition where controllers could exercise Data Link made further new strategies possible. As discussed in the above sections, various attempts were made to record and evaluate the approaches developed by study participants. In this section, the potentially useful strategies used and suggested by the controllers are summarized.

In general, Data Link was agreed to be a suitable mode of communication for MT clearances (altitude assignments, heading changes, and speed changes) and for TI messages, but not for instructions requiring precise timing, conflict resolutions, or the handling of missed approaches. Strategies included sending messages earlier to compensate for the Data Link delays and bypassing menus in heavy traffic conditions. Controllers switched to voice in situations where time was a critical factor, such as vectoring aircraft to inner fixes and finals or after pilot errors occurred. Half of the controllers said they preferred voice over Data Link when working alone.

Under the team condition, strategies were more varied, but all controllers reported extensive use of Data Link. In most situations, one controller was considered to be the primary controller who always used voice, but may or may not have used Data Link. He usually handled turns to finals and approach clearances. The secondary controller always used Data Link, but may or may not have used voice. He generally used TI and MT lists for outer fixes and clearances, took handoffs, gave preliminary instructions, and,

in some cases, repositioned data blocks. None of the teams shared the radio frequency.

### 3.2.1.5  Projected Effects of Controller Team Size.

The final technique that was used to explore controller strategies and their perceived effectiveness was a post-test comparison of the four test conditions on the dimensions of individual controller workload, system capacity, and safety.

The data obtained from each subject were transformed to produce relative values on a normalized ratio scale for each of the four conditions using a version of the AHP. The AHP uses data obtained from sets of relative judgments rather than independent absolute judgments to quantify subjective data. Each item to be evaluated is compared with all other items and the data are represented in a judgment matrix in which each row or column reflects one item's dominance relative to all other items. The geometric means method is used to calculate the scale values which represent the position of the item on a scale relative to all other items in the comparison. In the following analyses, the means of the eight subject's values on the AHP scale were compared for each combination of communication condition and number of controllers at the sector. The statistical significance of the relative differences among the conditions was tested for individual controller workload, capacity, and safety.

Statistical analysis of the AHP scale workload means indicated that the perceived level of individual controller workload was not significantly affected by the communication condition, $F(1, 7) = .04$, $p = .83$, or the number of controllers at the sector, $F(1, 7) = 4.06$, $p = .08$. In addition, no statistically significant interaction between communication condition and number of controllers was detected, $F(1, 7) = 1.61$, $p = .24$.

These findings are consistent with a majority of the design development studies that have been conducted with Data Link controllers which show either no effect of Data Link on perceived workload, or a mild reduction in comparison to voice-only conditions. Variations in controller workload associated with voice and Data Link comparisons in different studies appear to be closely linked to the difficulty of the ATC problem, the degree to which the ATC problem is structured to take advantage of Data Link's ability to simplify the issuance of routine messages, and training level on the use of Data Link.

In contrast to the workload data, the capacity dimension subject ratings were significantly affected by the number of controllers at the sector. While the overall difference between communication conditions was not significant, $F(1, 7) = 1.09$, $p = .32$, two controllers were judged as being capable of producing higher overall capacity of the ATC system than one controller at the

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combined sector, $F(1, 7) = 6.77$, $p = .03$. However, the interaction between communication condition and number of controllers also was significant, $F(1, 7) = 8.40$, $p = .02$.

As suggested by figure 3, and confirmed by planned comparison analysis of the interaction means, this finding indicates that controllers felt that the two-controller team was capable of increasing capacity, but only when the voice system was supplemented by Data Link.

Controller comments recorded on the rating sheets and during debriefings were consistent with this interpretation. Several subjects noted that capacity is ultimately determined by the acceptance rate at the airport. However, it also was stated that Data Link has the potential to increase capacity in some conditions with two controllers because it will provide a second communication channel that could be used by an assistant controller to handle routine duties (e.g., TC, TI service). Thus, the primary controller may have an improved capability to produce small capacity increases by preventing gaps in the arrival stream. Other comments suggested that the second controller also may be able to increase capacity by using Data Link to maintain traffic flow when the primary controller is required to devote complete attention to resolving a separation problem or pilot error occurring on the final approach.

The results on the ATC safety dimension showed that Data Link was perceived as producing higher system safety than voice-only communications, $F(1, 7) = 8.14$, $p = .02$ (see figure 4). While no significant difference was detected between the one- and two-controller conditions ($p = .053$), analysis of the significant interaction $F(1, 7) = 15.97$, $p = .005$ suggests that the effect of Data Link on safety was largely confined to the situations in which two controllers were at the sector.

These data also are consistent with subject opinions recorded on the questionnaire. While two controllers at a voice sector cannot improve communications on a single channel, it was noted that some improvement in safety might have been realized by the "extra pair of eyes." However, with Data Link, the second controller provided this monitoring function in addition to offloading routine communications from the primary controller. Furthermore, it appeared that the general advantages of reduced confusion and communication error that were achieved with Data Link might have been most apparent when the second controller was added to the sector to assume routine communications.

These post-test data as well as adjunct debriefings appear to provide some initial direction in the current effort to discover strategies and procedures which will optimize the benefit of implementing Data Link in the terminal ATC environment. The subjects' rating responses were based on a combination of their
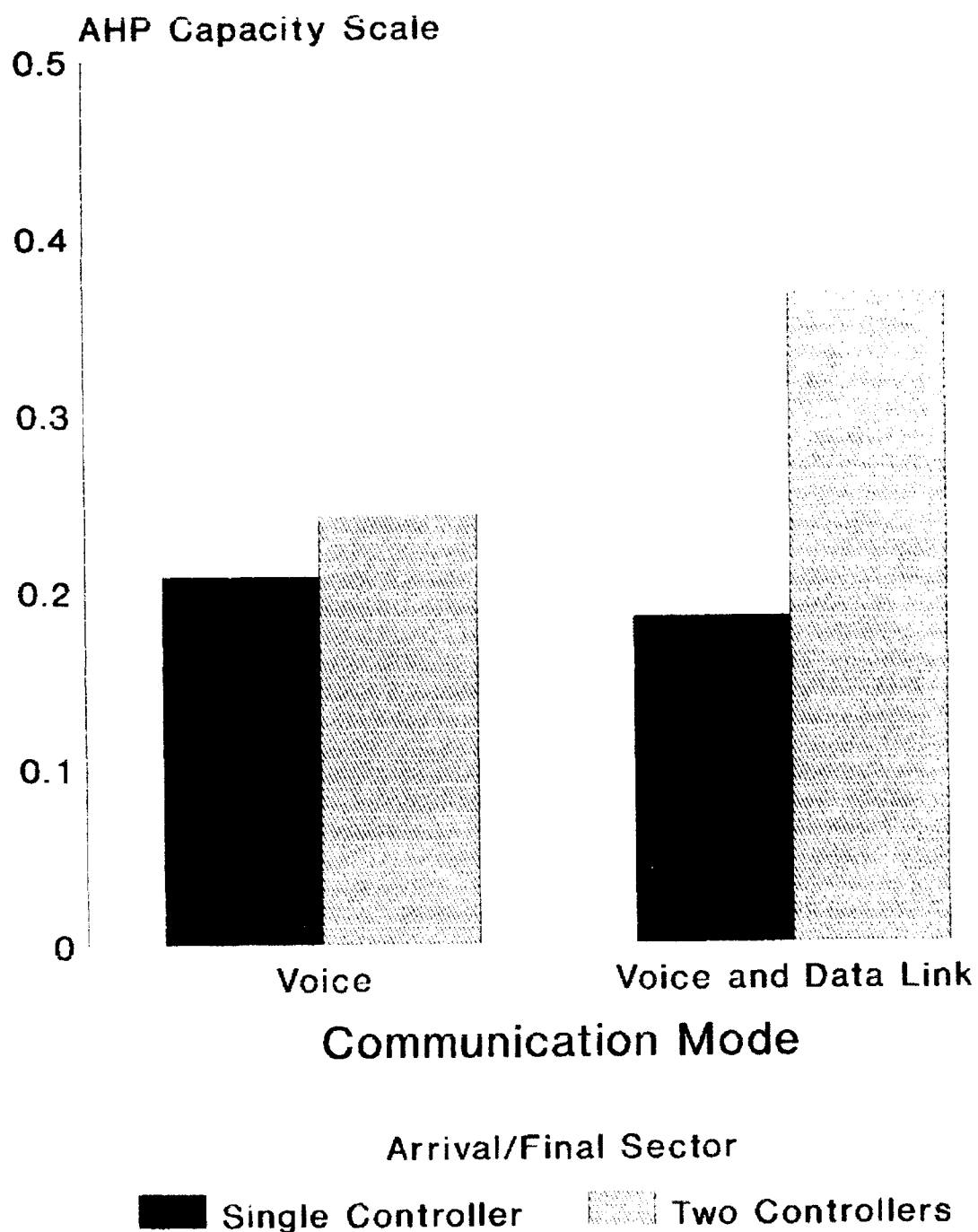
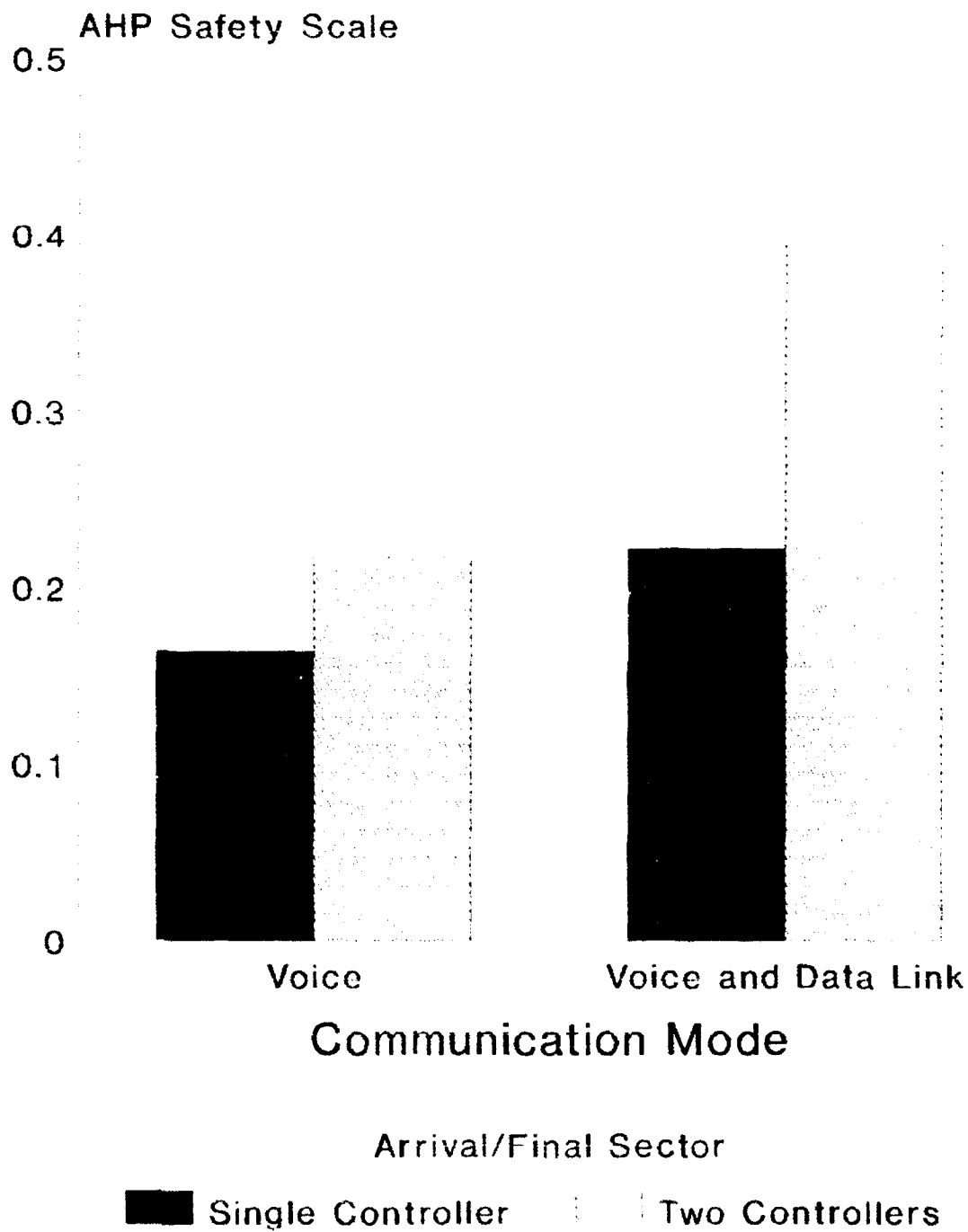FIGURE 3. PROJECTED EFFECTS OF TEAM SIZE ON CAPACITY

FIGURE 4. PROJECTED EFFECTS OF TEAM SIZE ON SAFETY

operational expertise in performing terminal ATC tasks and reflection on their experiences in the Data Link Test Bed during which they experimented with the use of voice and Data Link under unconventional conditions. The test runs were not designed to test the operational feasibility of combining arrival and final approach sectors or the use of multiple controllers at such sectors. Rather, the situation was devised in order to permit the controllers to explore options for using Data Link which might not have been apparent under more typical ATC conditions.

The data collected from the questionnaire indicate that one way in which the benefits of Data Link can be enhanced is through the use of controller teams. These projected benefits of increased safety and capacity appear to be primarily attributable to the fact that Data Link provides a second communication channel to the controller. While the second channel may be beneficial to a single controller, it appears that these benefits are multiplied when a second controller is added. Such benefits seem to be greatest under special conditions when the assistant can use Data Link to: (1) send routine messages during periods of high traffic load, and (2) help to avoid traffic delays by using Data Link to maintain traffic flow while the primary controller deals with an error condition or emergency. The data does not indicate that two controllers are needed to benefit from Data Link. The data does show that Data Link presents the possibility of devising new ATC conventions and strategies which make optimal use of the second communication channel offered by this system. The results support the concept that test scenarios and associated experiments should be designed which can be used to isolate the conditions under which these expected benefits can be observed and measured using both controller judgments and performance measures.

### 3.2.2  Evaluation of Performance Measures.

As discussed in section 2.1 of this report, the full scale test runs conducted in Mini Study 3 were designed primarily to provide the controllers with a complex, high density air traffic situation in which alternative strategies for employing Data Link could be explored. Candidate performance measures were collected during the study in order to evaluate their potential for valid application in future operational evaluation research. Unlike the exploratory and developmental focus of the study reported here, operational evaluation studies will be designed to assess and document the impact of the initial terminal Data Link services on the overall performance of the ATC system. Performance measures such as those discussed in the following subsections of this report will be needed to objectively evaluate Data Link's effects on system safety, capacity, and efficiency, as well as its efficacy in reducing congestion of the voice radio channel.

It must be emphasized that the goals and subsequent design of the current study narrowly restrict interpretation of the performance

data reported here to issues associated with the value and appropriateness of the candidate measures themselves. For the reasons discussed below, no conclusions drawn from these data regarding the impact of Data Link on ATC performance are warranted or valid:

   a. Controller practice and familiarity with the test airspace and with Data Link inputs and displays were extremely limited, and did not provide subjects with the level of knowledge and facility that will be required of subjects in an operational evaluation study. In such studies, sufficient training will be required to approximate skill levels that will be the norm for controllers using a fielded system.

   b. The performance measures tested in this study were influenced by the intentional omission of standardized procedures and rules for using Data Link. In order to examine strategy issues, subjects were explicitly instructed to freely experiment with alternate uses of the system in a manner which would not be appropriate for a simulation intended to provide data aimed at accurately predicting the operational impact of Data Link.

   c. As evidenced by the findings of the subject interviews conducted during full scale testing, errors and performance variations that were not attributable to the communication systems were introduced by simulation pilots in this study. Drawing valid conclusions about Data Link from performance metrics during operational evaluation will require the use of more highly trained simulation pilots, improved simulation pilot procedures and displays, and the participation of a subgroup of actual aircraft pilots in the test scenarios.

In the data reported in the following subsections, a repeated measures procedure was used for analysis of statistical significance. The Huynh-Feldt correction to the degrees of freedom for the within-subjects Multivariate Analysis of Variance (MANOVA) was applied, when appropriate, to correct for correlations between repeated measures.

## 3.2.2.1  ATC System Safety Measures.

The primary technique proposed for assessing safety in future operational evaluations involves the use of algorithms which will automatically detect and record the occurrence of conflicts and their severity. Prior test applications of these techniques have indicated that their sensitivity to aircraft proximity tends to produce a large number of false alarms. Thus, interpretation of the data required extreme caution and detailed qualitative analysis of the aircraft track records to determine the validity of a detected conflict, its cause, and operational significance. The results of the current study confirmed this conclusion.

A majority of the automatically detected conflicts were eliminated from the raw NSSF data file using a set of rules designed to filter out false alarms. The shortened list contained several conflicts with low API's and high CPA's. All of these potential conflicts were between aircraft within a sector rather than between aircraft in two different sectors, and a majority occurred in the combined arrival/final sectors.

Qualitative analyses were conducted on the 10 conflicts with API's greater than 40. Three of these were discounted as attributable to scenarios problems or recording system errors, and were not related in any way to controller activities. Of the remaining seven conflict detections, four occurred in the single controller conditions (two in voice and two in Data Link). No conflicts were detected in the team voice conditions and three in the team Data Link conditions. However, analyses of the aircraft track and communications records did not indicate that the communications conditions under which the potential errors were detected were a causal factor in either the single controller or team conditions.

Further evidence supporting the need for qualitative analysis as well as automatic recording of conflicts in future operational evaluations was obtained from notes that the controller subjects were asked to maintain of separation violations that they detected during the test runs. The controllers recorded a total of 21 conflicts of which 13 did not appear on the filtered NSSF listing. Three of the seven NSSF conflicts with API scores over 40 were contained in the controller lists.

## 3.2.2.2  ATC System Capacity Measures.

The number of aircraft a controller is able to handle over a period of time while employing a given ATC technology was selected as one of the primary candidate measures of system capacity for future operational evaluation. Otner measures tested in this study for assessing capacity included aircraft spacing on final approach, time between landings, and number of aircraft crossing the runway threshold per unit time.

The data for number of aircraft handled were separated into individual and team conditions for the arrival/final sectors. The number of aircraft handled per run was divided by the total number of minutes in the session to adjust for different scenario lengths. The departure sectors were not tested because traffic load was held constant during all scenarios.

A MANOVA was used to test the one between-subjects variable and one within-subjects variable design for the single controller arrival/final runs. The analysis showed that the main effect of communication type was not significant, $F(1, 4) = .28$, $p = .6256$, but indicated that the effect of side of airspace was significant,

$F(1, 4) = 10.07$, $p = .0337$. The interaction of the two factors was not significant, $F(1, 4) = 1.32$, $p = .3141$.

The results for the team arrival/final runs indicated that the main effect of communication type on number of aircraft handled per minute was not significant, $F(1, 4) = .68$, $p = .4553$, and that the effect of side of airspace was not significant, $F(1, 4) = .002$, $p = .9694$. The interaction of the two factors was also not significant, $F(1, 4) = 1.32$, $p = .3141$.

Aircraft spacing on final also was measured to assess its value as a measure of capacity. As each arriving aircraft crossed the runway threshold, the straight-line distance to the next arriving aircraft was calculated. A potential limitation of this method is that aircraft injected into the approach stream between two others shortly after a measurement had been taken would not immediately turn up in the file of spacing data. However, it was expected that the improvement in spacing would be counted as the injected aircraft landed. To test for the impact of this factor on the spacing measure, the rumber of aircraft injected into the normal arrival flow during the full scale simulation runs were counted. Injected aircraft events only occurred 10 times out of a possible 531 landings. Thus, it appears that the spacing measure will be minimally affected by this possibility in future evaluations.

Another related technique for assessing capacity was to consider elapsed time between landings. Given that traffic density was increasing as a function of simulator time in each scenario, it ·as assumed that, if the spacing and timing measures were valid indicators of capacity, some decrease would automatically occur as each scenario progressed.

Average spacing and timing on final for each controller were averaged over 1,000 second "windows" during each simulation. The data were submitted to statistical testing using MANOVA. The results indicated that, for individual Data Link and voice data, there was no significant effect of communication type or side of airspace on spacing, $F(1, 4) = .76$, $p = .4331$, $F(1, 4) = 11.58$, $p = .0735$. The interaction of scenario time and side was also not significant, $F(1, 4) = .15$, $p = .7183$, and there was no effect of scenario time on spacing, $F(2, 4) = 3.6$, $p = .0768$.

There was also no significant effect of communication type or side of airspace on time between landings, $F(1, 4) = 1.73$, $p = .2587$, $F(1, 4) = 4.67$, $p = .0967$. The interaction of scenario time and side was also not significant, $F(1, 4) = .8$, $p = .4214$, and there was no effect of scenario time on time between landings, $F(2, 4) = .92$, $p = .4353$.

For the team Data Link and voice data, there was no significant effect of communication type or side of airspace on spacing, $F(1, 4) = .32$, $p = .5998$, $F(1, 4) = 6.69$, $p = .0609$. The interaction

of scenario time and side was also not significant, F(1, 4) = .3.86, p = .1208, but there was a significant effect of scenario time on spacing (as shown in figure 5), F(2, 4) = 4.8, p = .0422.

There was no significant effect of communication type or side of airspace on time between landings, F(1, 4) = 3.05, p = .1555, F(1, 4) = 1.85, p = .2452. The interaction of scenario time and side was also not significant, F(1, 4) = .1.0, p = .3734, but there was a significant effect of scenario time on time between landings (as shown in figure 6), F(2, 4) = 4.57, p = .0474.

The above statistical tests demonstrate that the measures of spacing on final and time between landings should be sensitive to effects of communications technology evaluated in future operational evaluation studies. The measures successfully reflected the expected impact of increasing traffic density over the course of the simulation runs under team conditions. The fact that the effects were confined to the team controller test conditions can be seen as further evidence that the measures will validly assess capacity, since they appear to have shown the contribution of the additional controller to the ability to effectively respond to increasing traffic levels.

The rate of landings also was tested as a measure of capacity. To obtain this measure, the number of aircraft landed in the arrival/final sectors during each run was calculated. Statistical analysis detected no significant effect of communication type for the individual controller runs, F(1, 4) = 4.02, p = .1158 or for side of the airspace, F(1, 4) = 5.14, p = .0861. There also was no significant effect of the interaction of communication condition and side of airspace, F(1, 4) = 2.02, p = .2279.

The results for the team runs for rate of landings also showed no significant effect of communication type, F(1, 4) = 2.81, p = .1691, but there was a significant difference between side of airspace, F(1, 4) = 17.6, p = .0137. There was no significant interaction of communication type and side of airspace, F(1, 4) = 5.07, p = .0876.

3.2.2.3 ATC System Efficiency Measures.

As candidate measures of efficiency, the NSSF system measured the amount of time an aircraft spent in each sector and how far it flew (between controller acceptance and handoff). Times and distances can be expected to be partially dependent upon controller style, especially in departure sectors where it is possible to handoff an aircraft early, if all necessary instructions have been given. However, if it is assumed that a given controller would use the same approach under both Data Link and voice conditions, any improvements in flight time or distance flown that are measured in future operational evaluations should be attributable to an advantage offered by one of the communication media.
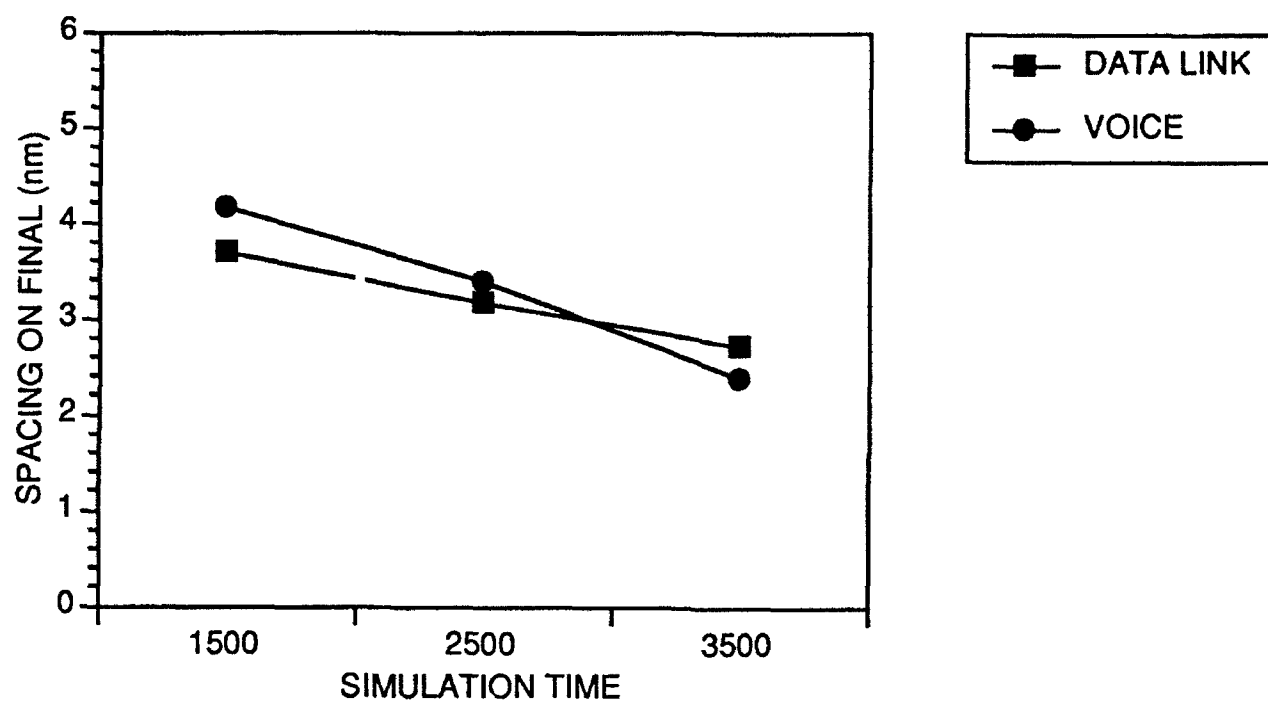
46

FIGURE 5. SPACING ON FINAL AS A FUNCTION OF PHASE OF SIMULATION
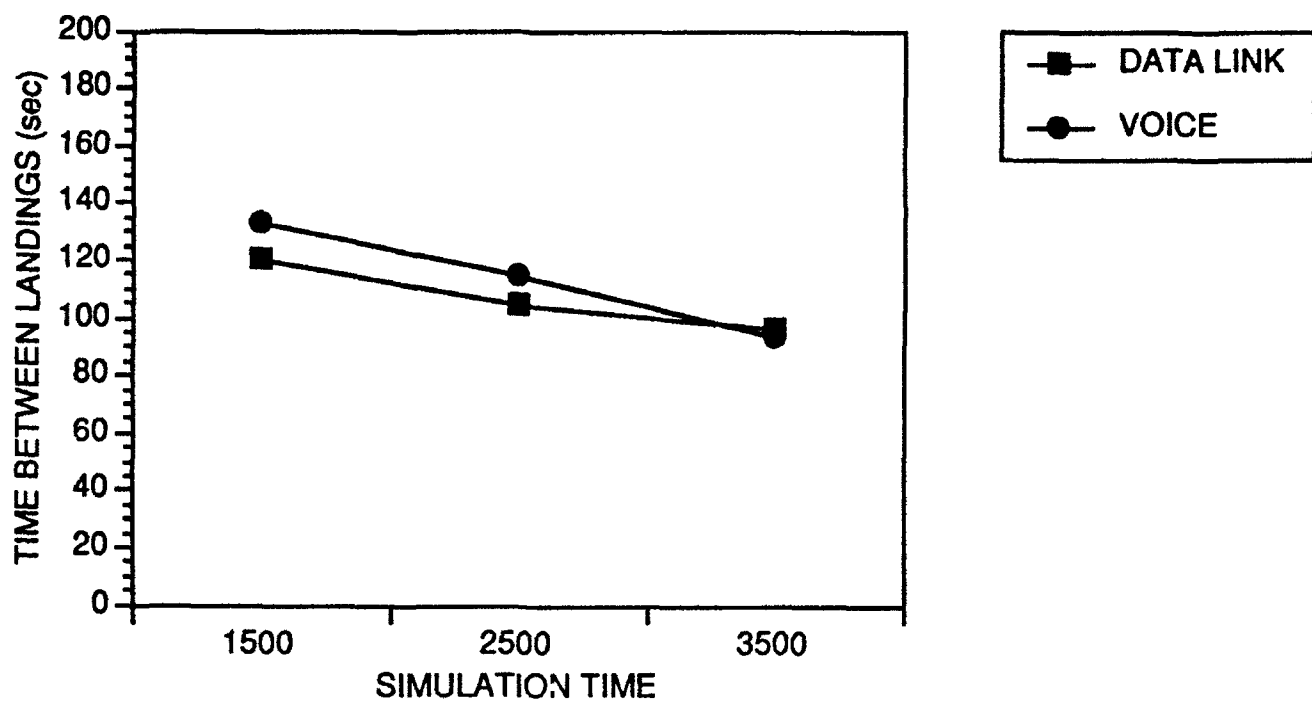
FIGURE 6. TIME BETWEEN LANDINGS AS A FUNCTION OF PHASE OF SIMULATION

A specific advantage of measuring time and distance while under control is the possibility of measuring how much controller intervention is required by each aircraft flight. In some sectors, improvements in communication may decrease the amount of "occupancy time" for each aircraft, thus freeing the controller to handle other aircraft. The following results suggest that this may be possible, but that the addition of a second communicating controller may confound the hypothesized relationship between flight time/distance and efficiency.

### 3.2.2.3.1 Flight Time.

Flight time data were divided into sets for individual versus team in arrival/final sectors. Departure sectors were considered separately and an independent analysis was conducted on each set. Only the first 25 aircraft were included in each analysis in order to eliminate those which started but did not complete their flight plans before the end of the simulation run. Flight time for each aircraft was measured and average flight time for each controller over each run was calculated.

A MANOVA for the individual arrival/final data showed that the main effect of communication type on flight time was not significant, $F(1, 4) = 5.94$, $p = .0715$, and that the effect of side of airspace was also not significant, $F(1, 4) = 1.0$, $p = .3728$. The interaction of the two factors was not significant, $F(1, 4) = .009$, $p = .9308$.

The results for the team arrival/final runs indicated that the main effect of communication type was significant, $F(1, 4) = 15.96$, $p = .0162$, and that the effect of side of airspace was not significant, $F(1, 4) = .19$, $p = .6845$. The interaction of the two factors was also not significant, $F(1, 4) = 1.9$, $p = .2392$. The results are plotted in figure 7.

The results for the departure sectors showed no significant main effect of communication type, $F(1, 6) = .08$, $p = .7876$, and a non-significant effect of side of airspace, $F(1, 6) = .22$, $p = .6541$. The interaction of the two factors was also not significant, $F(1, 6) = .31$, $p = .5957$.

The above statistical tests indicated that there were no significant differences in flight times under individual controller conditions, but that aircraft spent a longer time under control in the arrival/final sectors when the controllers worked in teams. This finding may be attributable to the fact that, unlike the voice-only team conditions, there were two controllers actively handling each aircraft in Data Link team conditions. Thus, the additional path changes, earlier acceptances, and later handoffs which may have increased flight time could reflect the ability of two controllers to relay more useful messages via Data Link to
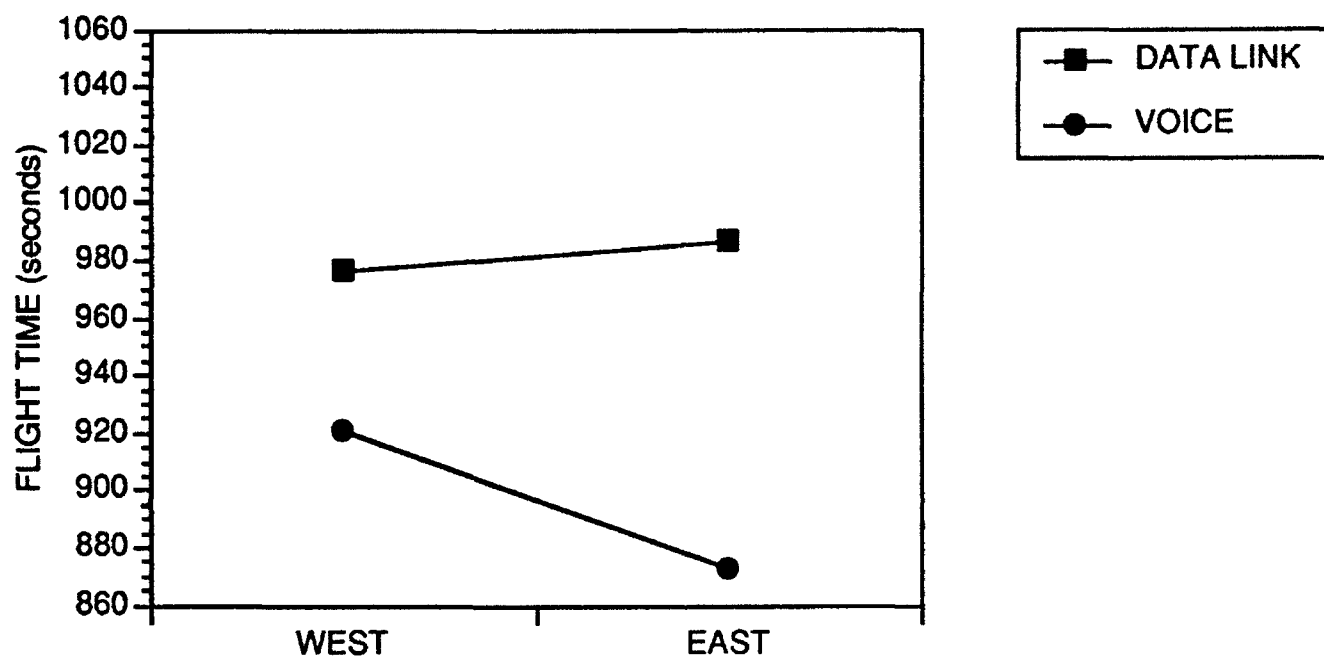
FIGURE 7. TEAM ARRIVAL/FINAL AVERAGE SECTOR FLIGHT TIMES

aircraft under high traffic conditions, rather than a difference in efficiency.

## 3.2.2.3.2  Distance Flown.

Average distance flown in each sector while under control was also measured.  Distance data for arrival/final sectors were separated into sets for individual versus team conditions.  Departure sectors were considered separately and an independent analysis was conducted on each set.  Only the first 25 aircraft were included in each analysis in order to eliminate those which started but did not complete their flight plans before the end of the simulation run.

A MANOVA was used to test the individual arrival/final runs and it was found that both the main effects of communication type, $F(1, 4) = 1.27$, $p = .3234$, and of side of airspace were not significant, $F(1, 4) = 6.81$, $p = .0595$.  The interaction of the two factors was also not significant, $F(1, 4) = .64$, $p = .4694$.

The results for the team arrival/final runs indicated that the main effect of communication type was significant, $F(1, 4) = 8.41$, $p = .0441$, and that the effect of side of airspace was marginally significant, $F(1, 4) = 7.6$, $p = .0511$.  The interaction of the two factors was not significant, $F(1, 4) = 3.38$, $p = .1397$.  The cell means are plotted in figure 8.

The results for the departure sectors were not significant for communication type, $F(1, 6) = .24$, $p = .6437$, or for side of airspace, $F(1, 6) = .01$, $p = .9082$.  The interaction of the two factors was also not significant, $F(1, 6) = .46$, $p = .5221$.

In parallel with the flight time data, the distance flown results indicate that in the team Data Link arrival/final conditions, aircraft flew farther while under control.  As suggested above, this pattern of results indicates that caution must be observed when using these measures for operational evaluation because rather than a drop in efficiency, the increase in distance and time may have been attributable to an increased level of communications effectiveness (e.g., earlier handoff acceptance would create longer distances and times).

## 3.2.2.4  Voice and Data Link Usage Measures.

## 3.2.2.4.1  Voice.

In previous studies in which communications measures were evaluated, use of the voice radio system to communicate ATC instructions to aircraft decreased with the availability of Data Link.  Radio usage was measured by totaling the amount of time controllers depressed the push-to-talk button in each position, for each scenario.  Frequency of use was calculated by counting
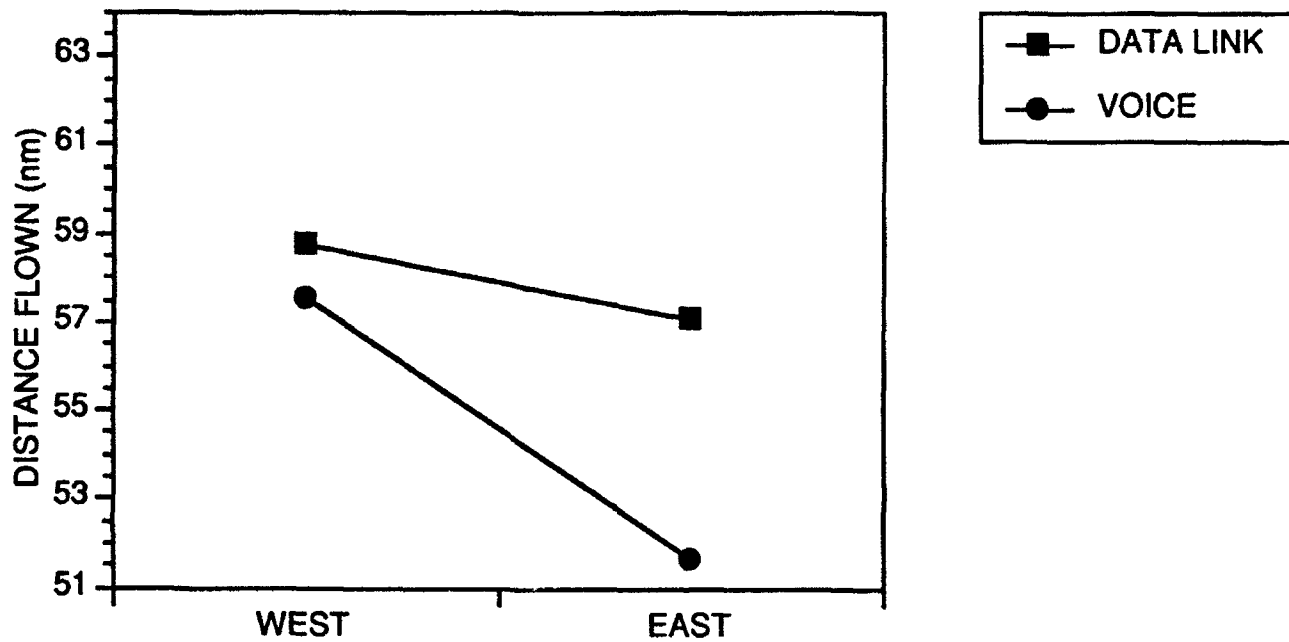
51

FIGURE 8.   TEAM ARRIVAL/FINAL AVERAGE DISTANCE FLOWN IN SECTOR

the number of times the microphone button was pressed and dividing by total scenario run time, to adjust for scenarios of different lengths. Because the measures of the duration of voice communication and frequency of use data were nearly identical in those studies, only the former was examined in the present study.

A test of the differences in the total duration of voice messages for individual arrival/final sectors, as shown in figure 9, resulted in a significant main effect of communication condition, $F(1, 4) = 12.45$, $p = .0243$, and a marginally significant difference between sides of the airspace, $F(1, 4) = 6.88$, $p = .0586$. Their interaction was not significant, $F(1, 4) = 2.57$, $p = .1845$.

During the team arrival/final runs, there was a significant main effect of communication type on total voice communication time, $F(1, 4) = 8.67$, $p = .0422$, but the effect of side of airspace was not significant, $F(1, 4) = 4.76$, $p = .0945$. The interaction of the two factors was also not significant, $F(1, 4) = .92$, $p = .3927$. The cell means are plotted in figure 10.

In the departure sectors there was a significant effect of communication type on total message duration, $F(1, 6) = 70.48$, $p = .0002$, but not for side of airspace, $F(1, 6) = 2.9$, $p = .1394$. The interaction of the two factors was not significant, $F(1, 6) = .21$, $p = .6660$. The cell means are plotted in figure 11.

*The results presented above confirm prior tests of measures of voice frequency usage.* As expected, under all test conditions the availability of Data Link communications with 80 percent of the aircraft produced significant drops in voice frequency usage. The consistency of this metric across several exploratory studies in both terminal and en route Data Link development indicates that it is likely to provide a valid quantitative indicator of the degree of Data Link's effect on voice frequency congestion in future operational evaluation studies.

3.2.2.4.2  Data Link.

To provide a candidate measure of the way in which Data Link is used by the controller, records of Data Link communications were reduced in order to count the frequency of MT, TI, and TC messages sent by controllers under various conditions.

Figure 12 shows the rate of sending Data Link MT and TI messages for the arrival/final sectors (no TC messages were sent in these positions). (Message frequency was divided by the total run time of each scenario to adjust for differences in scenario length). Figure 13 shows MT, TI, and TC messages for the departure sectors.

The data indicate that the rate of Data Link transmissions for MT messages was higher in the team condition while the rate of TI messages remained about the same for individual and team controller
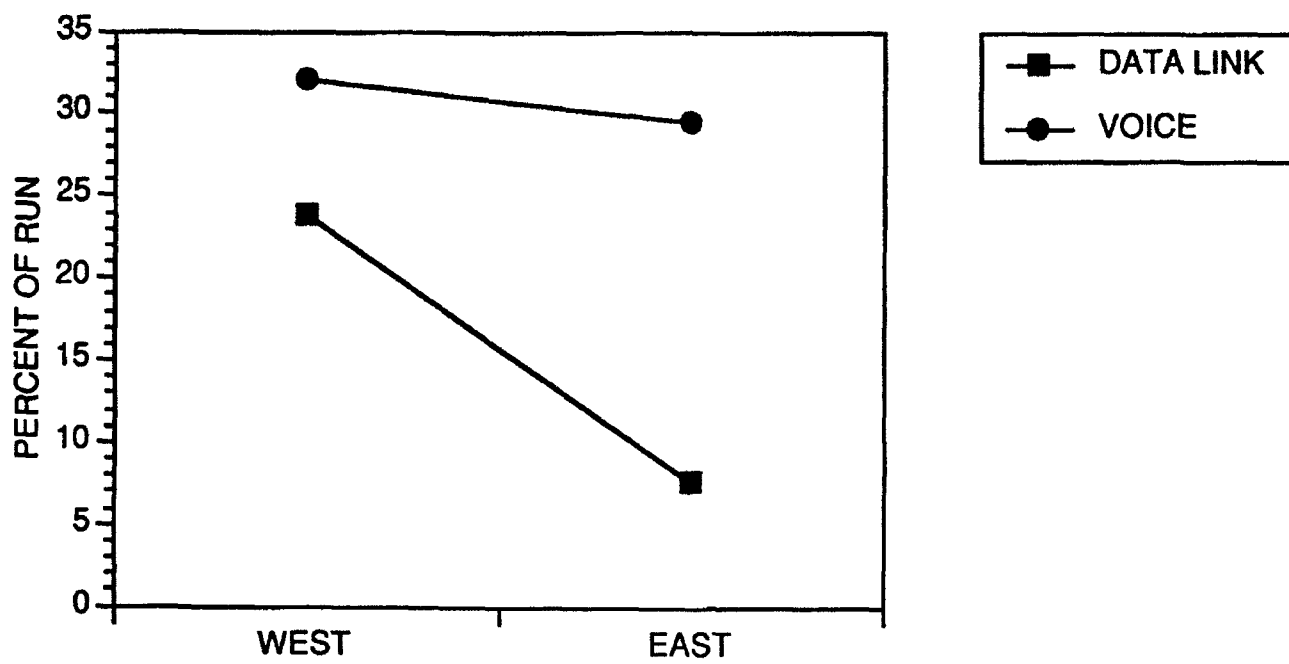
FIGURE 9.  TOTAL DURATION OF VOICE MESSAGES FOR INDIVIDUAL ARRIVAL/FINAL SECTORS
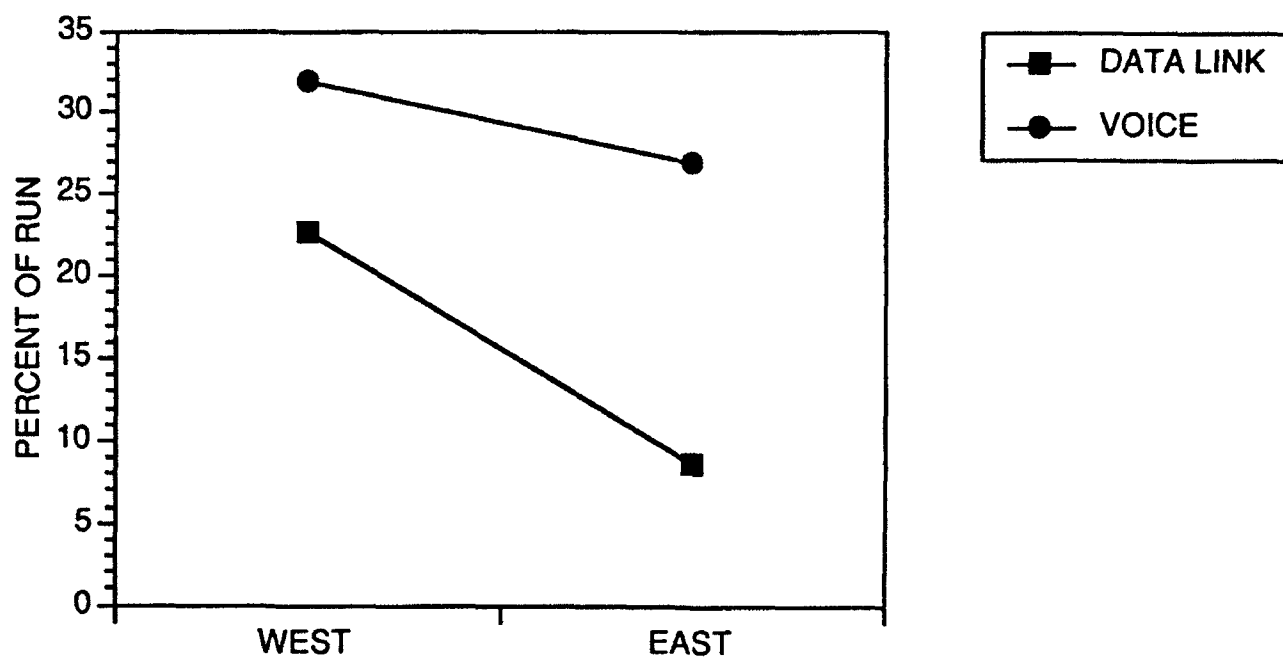
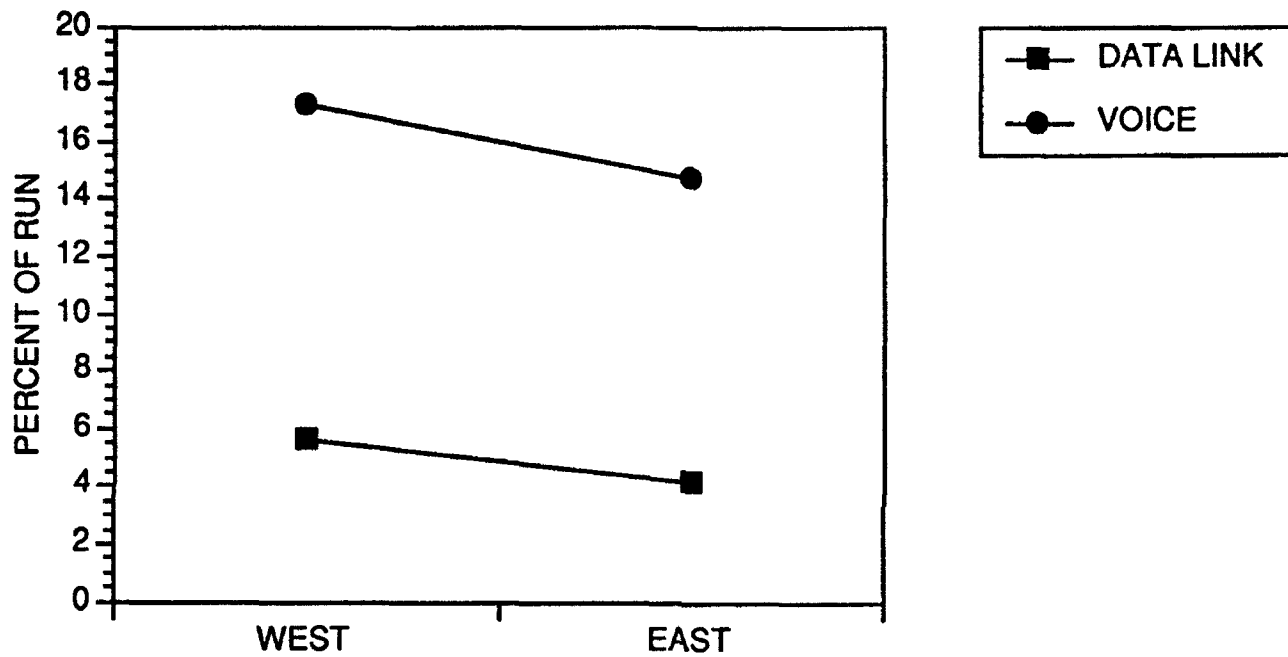FIGURE 10. TOTAL DURATION OF VOICE MESSAGES FOR TEAM ARRIVAL/FINAL SECTORS

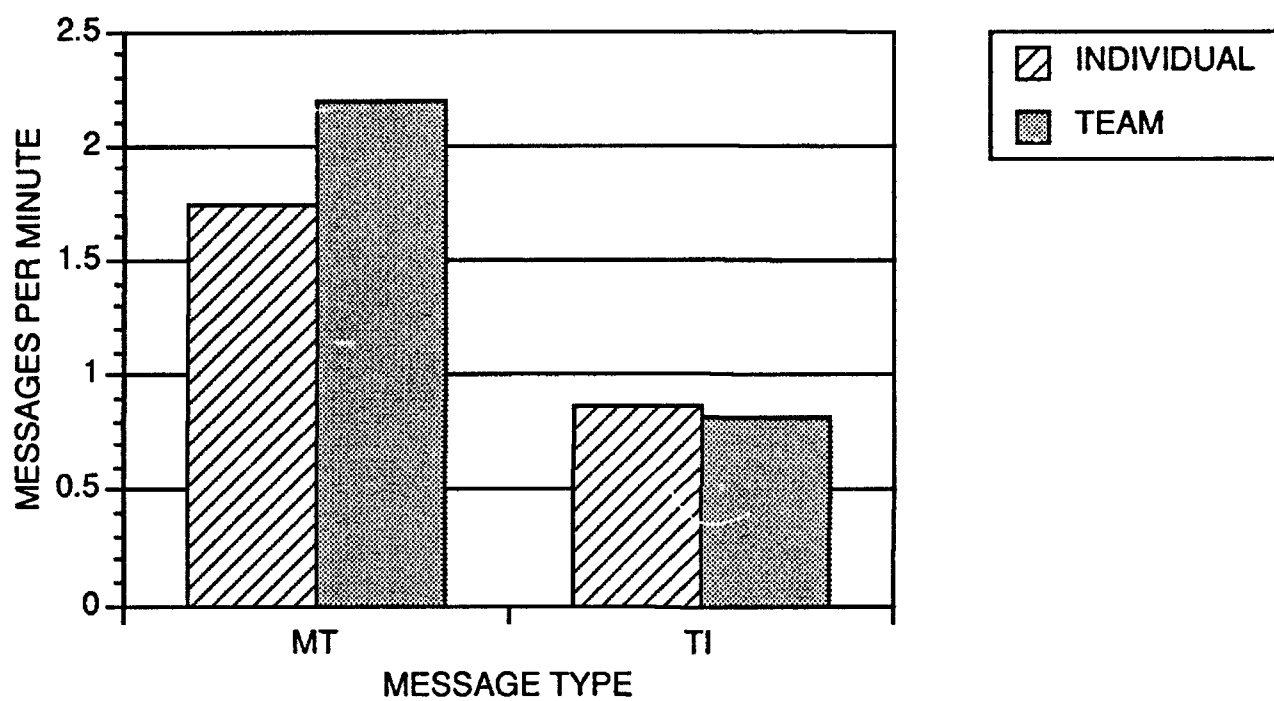FIGURE 11.   TOTAL DURATION OF VOICE MESSAGES FOR DEPARTURE SECTORS

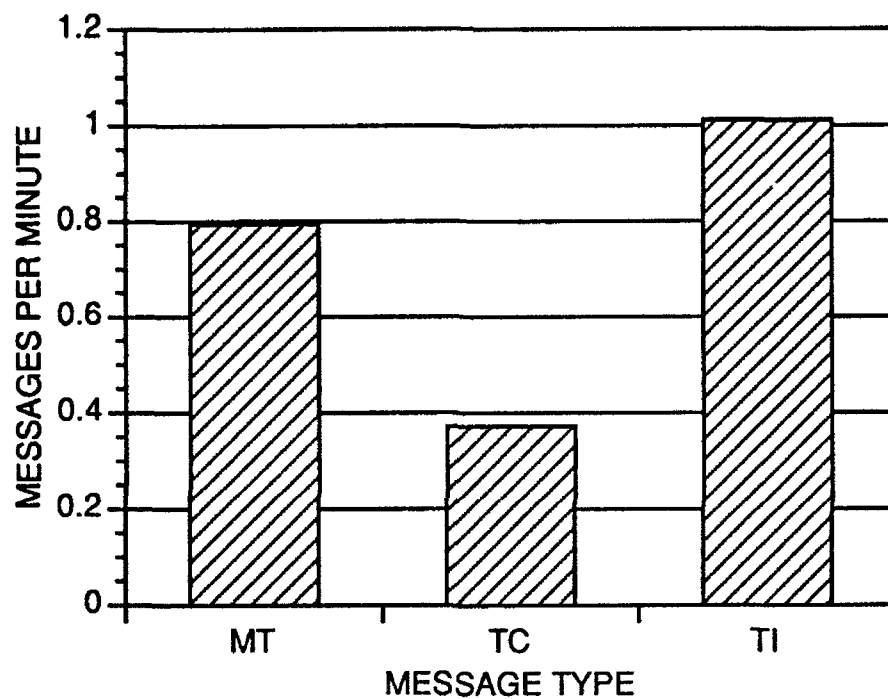FIGURE 12. RATE OF SENDING DATA LINK MT AND TI MESSAGES FOR ARRIVAL/FINAL SECTORS

FIGURE 13. RATE OF SENDING DATA LINK MT, TC, AND TI MESSAGES FOR
DEPARTURE SECTORS

configurations. Rates of message transmission in the departure sectors were generally lower and were in different relative proportions. Departure sector controllers sent more TI as compared to MT messages while the opposite was true in arrival/final sectors.

In Mini Study 2, videotape records were made of controller Data Link entries and it was found that an average of 3.7 seconds were required to key in a TI or MT selection, scroll the trackball to locate the cursor over the target aircraft, and press the ENTER key. In Mini Study 3, this average composition time was used to estimate the amount of time controllers spent formatting and transmitting Data Link messages.

Figure 14 shows the estimated average proportion of run time spent composing Data Link messages for arrival/final controllers in the individual and team Data Link with voice conditions. With the extra person available, it appears that Data Link was used somewhat more in the West side of the airspace. In the departure sectors, Data Link message composition took up 10.8 percent of the controller's time.

### 3.2.2.4.3  Voice and Data Link.

The use of time measurements to make a valid comparison of voice and Data Link in future operational evaluations must be approached with caution. While estimating Data Link message selection/composition times from keyboard activity observations is a relatively straightforward task, comparing these times to the time spent speaking on the voice radio presents complications. While both measures provide a total observable activity time, they do not necessarily reflect the time spent engaging in the mental activity required to generate the desired message. Such activity could precede the observed behaviors, or occur simultaneously with them. Thus, voice and Data Link comparisons may be misleading. In addition, while time measures are likely to be correlated with message length and complexity in the case of voice, selection of a lengthy message from a Data Link menu should take no more time than selection of a brief message. Therefore, comparisons will be strongly affected by the types of messages sent by controllers in a specific scenario.

Despite these limitations, the results from the preceding two sections were combined to examine the differences between speaking times and Data Link data entry times. The data for individual and team controller configurations were considered separately. Combining the data in this way assumes that the task of voicing an instruction to an aircraft is equivalent to keying an instruction into the Data Link system, and that the same types of messages were sent in both communications modes.
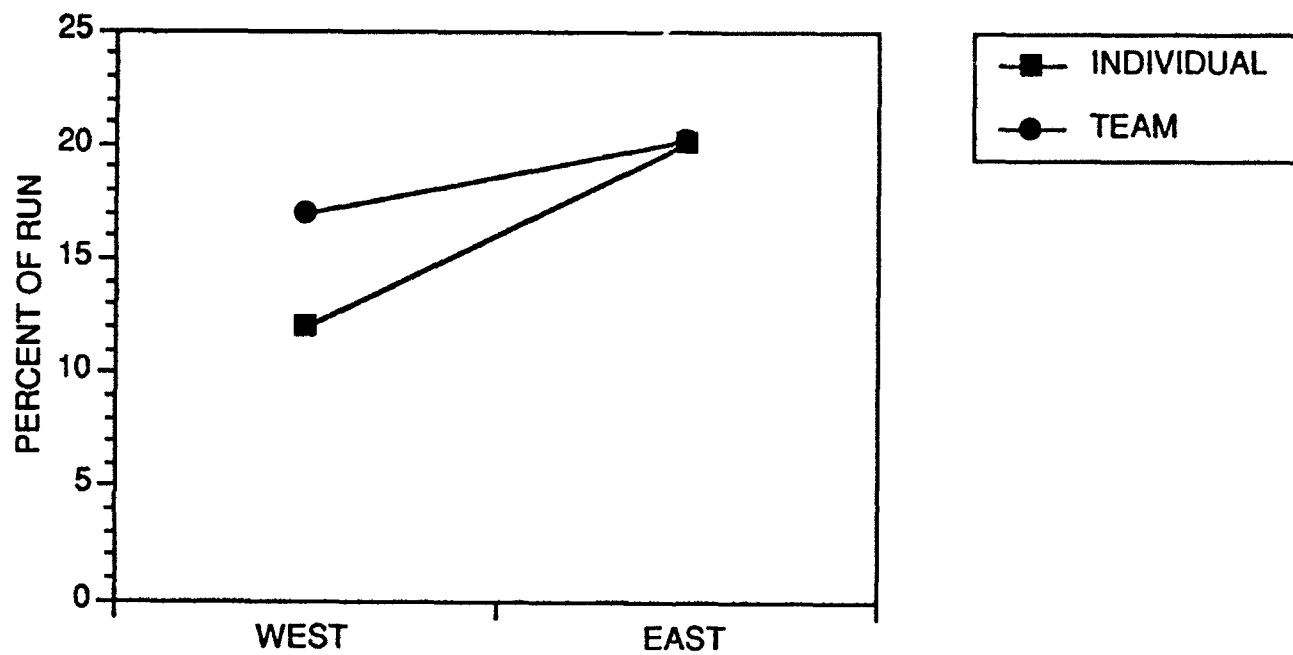
59

FIGURE 14.   ESTIMATED TOTAL TIME COMPOSING AND SENDING DATA LINK MESSAGES
FOR ARRIVAL/FINAL SECTORS

Figures 15 and 16 combine NSSF data for total length of voice transmissions in the arrival/final sectors (expressed as a proportion of total run time) with the time required to compose and send Data Link messages _estimated_ during the previous Data Link Mini Study. For the individual controller runs, there appears to have been little difference in the amount of time spent using a combination of Data Link and voice as compared to voice-only. However, in the team configurations, somewhat more total time may have been involved when Data Link and voice were both available, as might be expected with the provision of the second controller.

The results for the departure sectors tell a similar story when total time spent communicating was considered, as shown in figure 17. In the arrival/final sectors, Data Link messages made up about one-half of the time spent communicating during Data Link with voice runs. Departure controllers appeared to use Data Link more often when it was available, accounting for about two-thirds of total message time.

## 3.2.3 Discussion of Performance Measures.

### 3.2.3.1 Safety Measures.

The monitoring of predefined aircraft conflict parameters continues to be the only approach available for automated measurement of system safety in future operational evaluations. As shown in the present study, current methods for computerized conflict recording resulted in a number of false detections, and were not necessarily correlated with controller records of conflicts. Rule-based filters for excluding false alarms were developed for this study which proved successful for eliminating some incorrect detections. However, in order to decrease reliance on qualitative methods for screening automatically detected conflicts, additional filtering rules based on accepted ATC conventions may be needed. An alternative to such sophisticated screening rules addition that was tested in the present study is to restrict qualitative analyses to detected conflicts of long duration, high API, or low CPA. Such an approach should prove to be efficient for future tests of the impact of Data Link on safety. Additionally, efforts should be made to validate NSSF based conflict measures by comparing them to the conflict records provided by the ARTS system.

### 3.2.3.2 Capacity Measures.

The new approaches developed and examined in Mini Study 3 for assessing the effects of Data Link on system capacity in future operational evaluations included measures of spacing and time between landings on final and the rate of landings. The demonstrated sensitivity of these measures to increasing traffic demands in some test conditions suggests that they may be useful in operational evaluation. However, the results of the current study also indicate that the selection of appropriate measures of
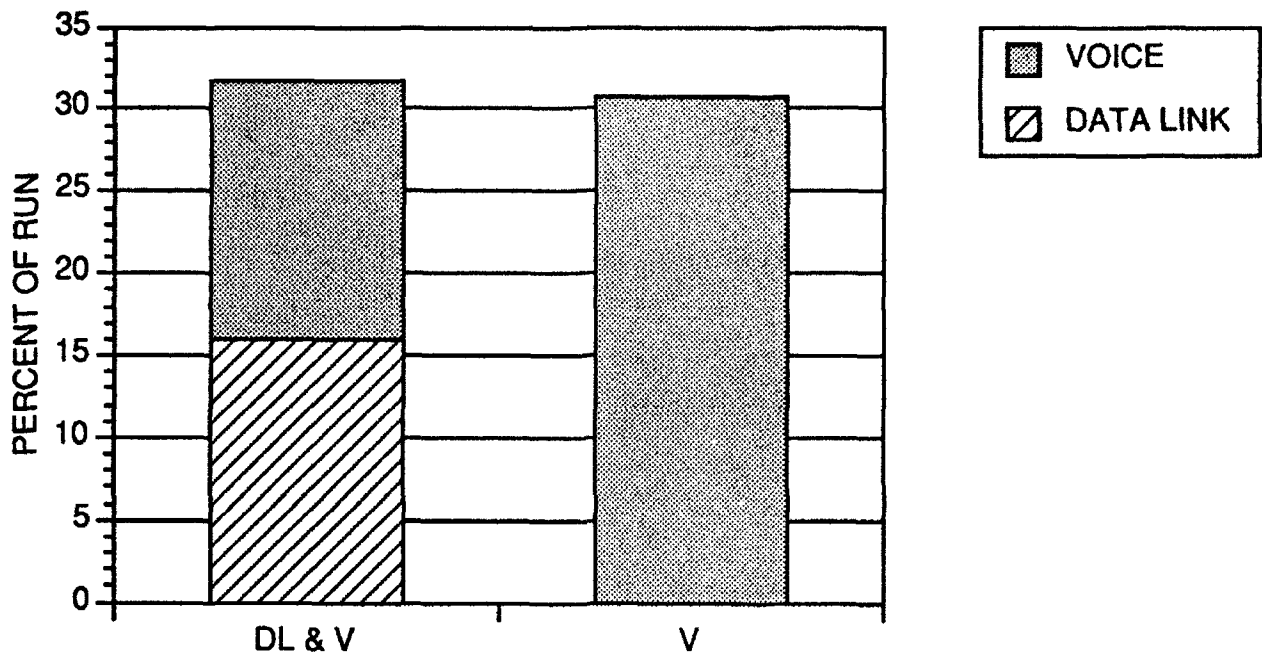
FIGURE 15. TOTAL TIME SPENT COMMUNICATING USING DATA LINK AND/OR VOICE
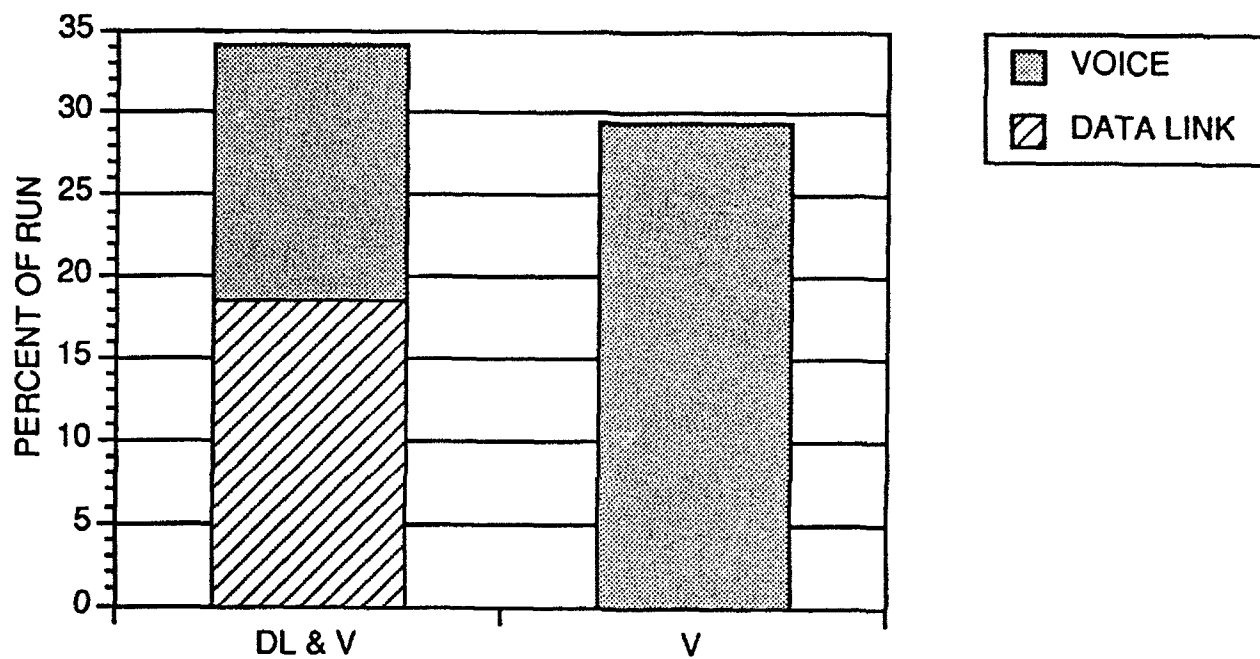IN THE INDIVIDUAL ARRIVAL/FINAL SECTORS

FIGURE 16. TOTAL TIME SPENT COMMUNICATING USING DATA LINK AND/OR VOICE
IN THE TEAM ARRIVAL/FINAL SECTORS
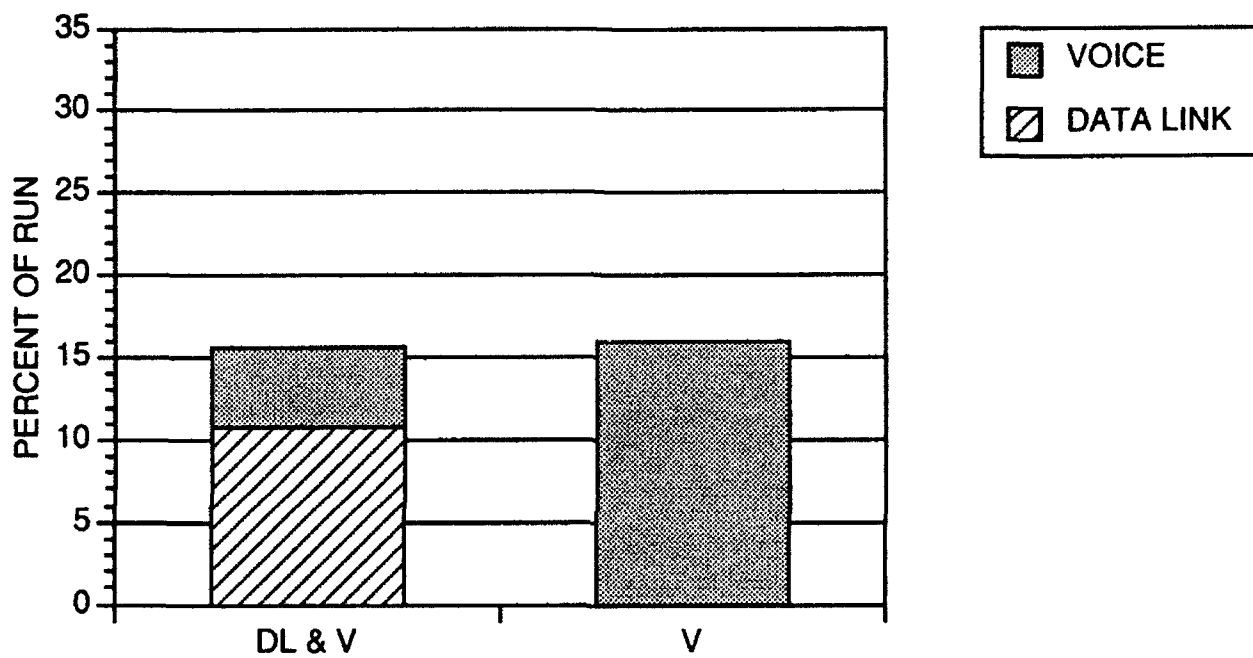
FIGURE 17.   TOTAL TIME SPENT COMMUNICATING USING DATA LINK AND/OR VOICE
             IN THE DEPARTURE SECTORS

capacity will depend upon how Data Link is employed by the test controllers.

For example, the current study yielded no significant differences between Data Link and voice on the tested system capacity measures. The strategy data indicate that this result is probably attributable to the way in which the controllers distributed messages between Data Link and voice. It appears that most controllers in Mini Study 3 did not use Data Link to negotiate the control of aircraft on final approach. Voice was preferred primarily for its rapid transmission and response capabilities. Therefore, controllers were using voice in both Data Link and voice scenarios to accomplish the tasks which would have the greatest effect on the spacing measures that were collected. The only benefit that Data Link could have in such situations would be to indirectly effect spacing on final by perhaps creating a more consistent traffic flow.

As suggested by the strategy data, it appears that additional, scenario-specific measures may be needed in operational evaluation to detect Data Link's hypothesized indirect effects on capacity produced by the ability to employ two available communications channels. Nevertheless, the measures employed during Mini Study 3 should continue to be used as general indicators of system capacity.

### 3.2.3.3  Efficiency Measures.

The performance measures of flight time and distance flown while under control are measures of efficiency that have a high level of face validity. However, as noted earlier, they must be interpreted in conjunction with measures of effectiveness and of controller strategies. Another measure of efficiency which should be considered is time and distance as measured between sector boundaries. Further investigation of measures of time and distance should be made to determine the best metrics for future Data Link studies.

A problem with conducting statistical analysis of the data from experiments such as Mini Study 3 is that some information is lost when averaging over observations. (In the case of efficiency measures, each aircraft's flight through a sector can be considered as an observation.) The statistical computations involved to use the observation data are very complex, especially in the case of the design employed in Mini Study 3. The analysis could be simplified for an operational evaluation with an experimental design which includes fewer factors.

### 3.2.3.4  Voice and Data Link Usage.

Although some voice traffic may occur to correct or modify Data Link transactions, there was still a substantial decrease in voice

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usage when Data Link was available. Measures of communications errors should be added to system usage measures in order to provide a complete measure of the comparative effectiveness of the voice and Data Link systems during operational evaluations.

Improved measures of message content identified by tne sending controller will also be desirable for operational evaluation research. Accurate comparisons of voice and Data Link will require efficient methods for analyzing the type and complexity of each message sent. Further efforts also should be made to develop computerized recording methods for capturing Data Link message composition durations and errors.

## 4. CONCLUSIONS.

The results of the study presented in this report warrent a number of specific and general conclusions regarding the initial terminal air traffic control (ATC) services, required changes to the service designs, controller strategies for maximizing the effectiveness of Data Link, the development of performance measures, and future research and development efforts.

Data Link Service Designs:

a. The design review phase of this study confirmed the acceptability and utility of the modifications to the initial terminal Data Link services that were based on the results of the November 1991 study. In addition, the design review generated a limited number of additional service enhancements for incorporation in Data Link Test Bed software and the functional design specification. Among the most important of the modifications recommended by the Air Traffic Data Link Validation Team (ATDLVT) controllers were improvements to the menu-based service designs intended to ensure maximum adaptability to the full range of field requirements. These included: (1) an increase in the flexibility with which terminal information (TI) and menu text (MT) items can be combined for uplink, (2) inclusion of automation and editing utilities to permit rapid adaptation and modification of items in the TI list, and (3) removal of restrictions on the number of items in the MT list that can be used for speed, heading, altitude, and multiple clearances.

b. The results of the design review also confirmed that human factors design features added to the MT and TI service have enhanced the usability of these menu-based services. Controller ratings of the impact of modifications aimed at reducing display clutter, improving the ease of item selection, and reducing item selection errors indicated that each of these features has the potential to improve controller performance.

c. Design debriefing results obtained after the full scale simulation exercise suggested that two general human factors issues

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warrant further consideration in the development of terminal Data Link ATC services. Controller comments indicated that significant input error potential may exist when composing speed, heading, and altitude clearances using the menu bypass function, and that messages sent by Data Link may be more easily forgotten than those transmitted by voice. The subjects agreed that if either of these hypotheses is verified in future research, the design of the user interface and/or application procedures should be modified to compensate for any verified decrement in performance.

Further research also is needed on the effect of Data Link on controller situation awareness. Study participants were concerned that extensive use of Data Link might interfere with keeping their "picture" of the traffic situation since scanning of the screen was disrupted by looking at Data Link menus and the keyboard. It is recognized that this concern may be at least partly attributable to insufficient training with Data Link operations.

Controller Strategies:

d. The results indicated that Data Link can be an effective tool when working in team conditions. Six of the eight controllers said they preferred Data Link when working with another controller on the combined arrival/final sector. The second controller was able to use the extra Data Link communication channel to assist the primary controller. The subjects noted that team Data Link could reduce delays in a busy traffic situation by using the second controller to send routine messages and/or to control traffic flow. In voice-only team conditions, controllers did not opt to share the single voice channel, and reported that no team advantage was obtainable under this condition.

e. Experimentation with team control concepts elucidated some of the strategic control options made possible by Data Link. These ranged from highly defined duties for each teammate to a sharing of all control tasks. Such strategies appeared to provide controllers with a wider range of methods for dealing with increased traffic loads than those available under the current single communication channel system.

While team control does not appear to be necessary to gain Data Link benefits, its advantages were more apparent under team conditions in the present study. If this concept were pursued in future work, further study of team interaction styles would be needed to determine the most effective management of roles and resources for optimum efficiency and safety. Comments made by participants suggested that more practice in working together would be needed to improve team effectiveness and safety.

f. Controller projections of operational impact indicated that team size would not effect individual workload, but that the availability of Data Link could permit a two-controller team to

achieve increases in system capacity and safety.  Both of these effects were attributed to the increased ability to make use of dual communication channels when two controllers staff a sector.

g.  Controllers continue to see the communication delay inherent in Data Link technology as a potential problem which may limit its use in some terminal applications.  During the strategy discussions, several controllers noted that Data Link was not suitable for time critical instructions in the arrival/final sectors, such as turning aircraft onto final or dealing with missed approaches or conflicts.  Data Link was said to be most effective for TI, MT clearances, altitude assignments, heading changes, and speed changes, but not for conflict resolutions or the handling of missed approaches.  Other than Data Link delays, the controllers noted that limited Data Link training time in the current study was responsible for other difficulties experienced in use of the system.

Performance Measures:

h.  A number of the performance measures evaluated in this study appeared to show promise for future application in operational evaluation where proposed Data Link benefits to the ATC system will be directly tested using the finalized service designs.

Automatic conflict detections continue to be the primary source of objective data regarding system safety.  However, as shown by this study, to be valid, these measures must be supplemented by qualitative analyses to determine the cause of a detected incident and its operational significance.  Several measures of capacity and efficiency were examined in this study.  While, in most cases, the testing conditions did not include manipulations that would conclusively demonstrate their sensitivity or validity, the results indicated that valid measures must be closely tied to the strategies used by subjects to control traffic and to the nature of the test scenario.  Finally, measures of voice radio usage produced results that were highly consistent with those obtained in earlier studies and, if supplemented by measures of communication errors and message content, are expected to be valid for use in future operational evaluation.

Simulation Procedures:

i.  The performance of simulator pilots appeared to create restrictions on controller performance and the kinds of strategies controllers used during experimental runs.  These problems appear to have been a function of the simulator pilot Data Link interface and training.  They are expected to be rectified in the new simulator pilot laboratory being installed at the FAA Technical Center, and should not be a limiting factor during operational evaluations.

In agreement with the findings of Mini Study 2, the present results also indicate that additional time should be allocated for controller training and familiarization with Data Link in order to draw valid conclusion in operational evaluation studies.

## 5. RECOMMENDATIONS.

The following recommendations for future actions under the Federal Aviation Administration (FAA) terminal air traffic control (ATC) Data Link program are derived from the results and conclusions of the present research:

a. The results of the design review conducted as part of this study indicate that the initial terminal Data Link ATC services have reached a high level of development. It is, therefore, recommended that after the limited modifications generated by the review have been implemented, these services be subjected to operational evaluation in the Data Link Test Bed. In this evaluation, thorough testing of all four services should be performed under high fidelity simulation conditions using a group of controllers who have not participated in the design development process. As a minimum, the operational evaluation should assess the operational suitability of the initial services, and assure that their implementation does not adversely affect the safety or productivity of the ATC system.

b. The present research indicated that the positive impact of terminal Data Link beyond the reduction in voice radio frequency congestion may be greatest in specific situations where a second communication channel could increase safety or prevent delays. For this reason, it is recommended that an adjunct study to the operational evaluation be performed to compare the effectiveness of voice-only procedures with a system supplemented by Data Link in the context of specially defined terminal scenarios. Among others, these test situations should include cases of a stuck microphone and scenarios in which pilot errors disrupt the normal flow of air traffic. As suggested by the results of the current study, this research also should explore the possibility of using controller team strategies to resolve these special problems.

c. As shown by the results of Mini Study 2 and confirmed in the present study, transaction times are a critical determinant of the utility of Data Link for sending many control clearances in the terminal environment. As a consequence, the value of the data collected in operational evaluation studies will be dependent on the extent to which transaction times accurately reflect those which would be experienced in an operational implementation. Because of this, it is recommended that research efforts be pursued to obtain reliable estimates of pilot response delays and Data Link system transmission times.

d.  In addition to operational evaluation research, specific research should be planned to investigate unresolved human factors issues which have emerged from this and other terminal Data Link studies.  The most important of these issues are: (1) the comparative potential for undetected communication errors in voice messages and Data Link messages initiated by manual entries, (2) the significance and performance impact of reports that short term memory for manually entered Data Link messages may be poorer than memory for messages spoken over voice radio, and (3) the impact on situation awareness of the increased "heads down" time incurred by the addition of Data Link inputs and displays to the controller's tasking.  Investigation of all three of these issues should consider how the effects of familiarity and practice may mitigate suspected problems.

e.  The present study revealed a number of requirements for improvements in experimental methods and measurement techniques that should be addressed to enhance their utility in future simulation studies.  The following modifications are recommended: (1) increase controller training on Data Link procedures and airspace to more closely approximate operational levels of expertise, (2) take steps to improve simulation pilot performance, (3) explore improved methods for evaluating efficiency, communication error, and situation awareness, (4) improve experimental power through more efficient study design and analysis techniques, (5) improve data extraction from the simulation computers, and (6) exercise the experimental performance measures used in Data Link studies in the context of other ATC research to assist in validation.

6.  BIBLIOGRAPHY.

Billings, C. E. and Reynard, W. D., Dimensions of the Information Transfer Problem, in C. E. Billings and E. Cheaney (Eds.), Information Transfer Problems in the Aviation System, NASA Technical Paper 1875, National Aeronautics and Space Administration, 1981.

Computers to Reshape Air Control Job in 90's, New York Times, July 29, 1988.

Data Link Development Team, Controller Evaluation of Initial Data Link Terminal Air Traffic Control Services: Mini Study 1, DOT/FAA/CT-90/29, January 1991.

Shingledecker, C. A., Human Factors Research in the Development of Data Link Air Traffic Control Services, Proceedings of the Aeronautical Telecommunications Symposium on Data Link Integration, ARINC/FAA, 1990.

Talotta, N. J. et. al., <u>Controller Evaluation of Initial Data Link Terminal Air Traffic Control Services: Mini Study 2</u>, FAA Technical Center, DOT/FAA/CT-92/2, Volumes 1 and 2, June 1992.

APPENDIX A

AIRSPACE DESCRIPTION

ZDC

**100**
**SFC**

ZDC

ZDC
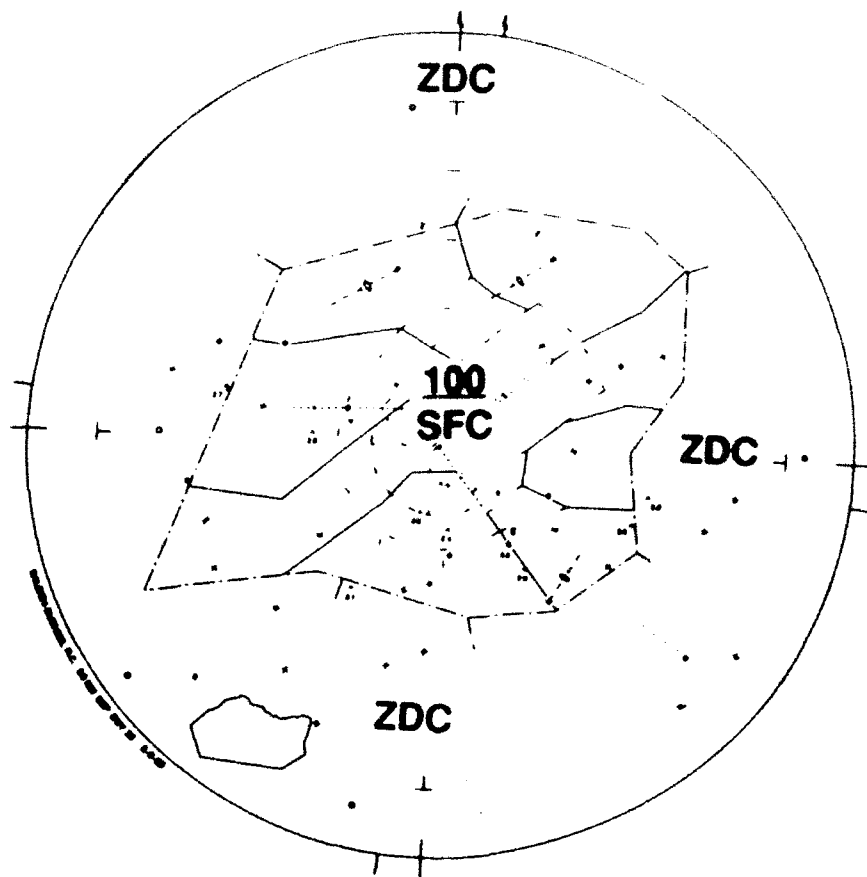
**Raleigh-Durham Approach Control is responsible for the outlined airspace surface to 10,000 feet.**
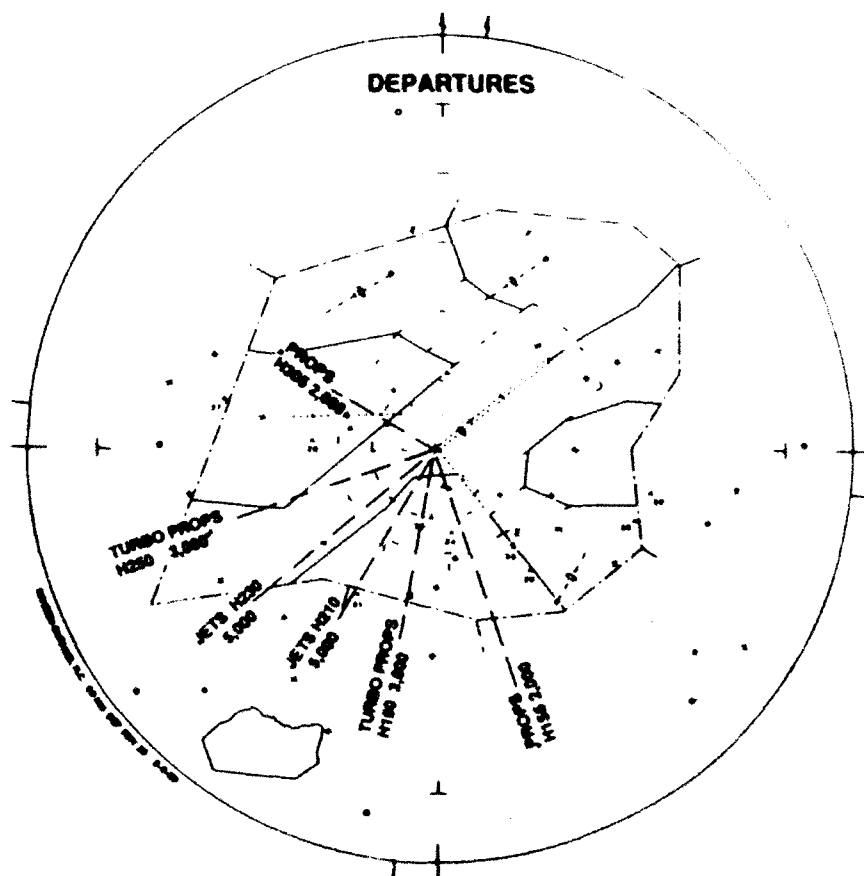
DEPARTURES

**Departure headings assigned to aircraft from Raleigh-Durham Runways 23R and 23L.**

A-1

**NORTH DEPARTURE ALTITUDES**
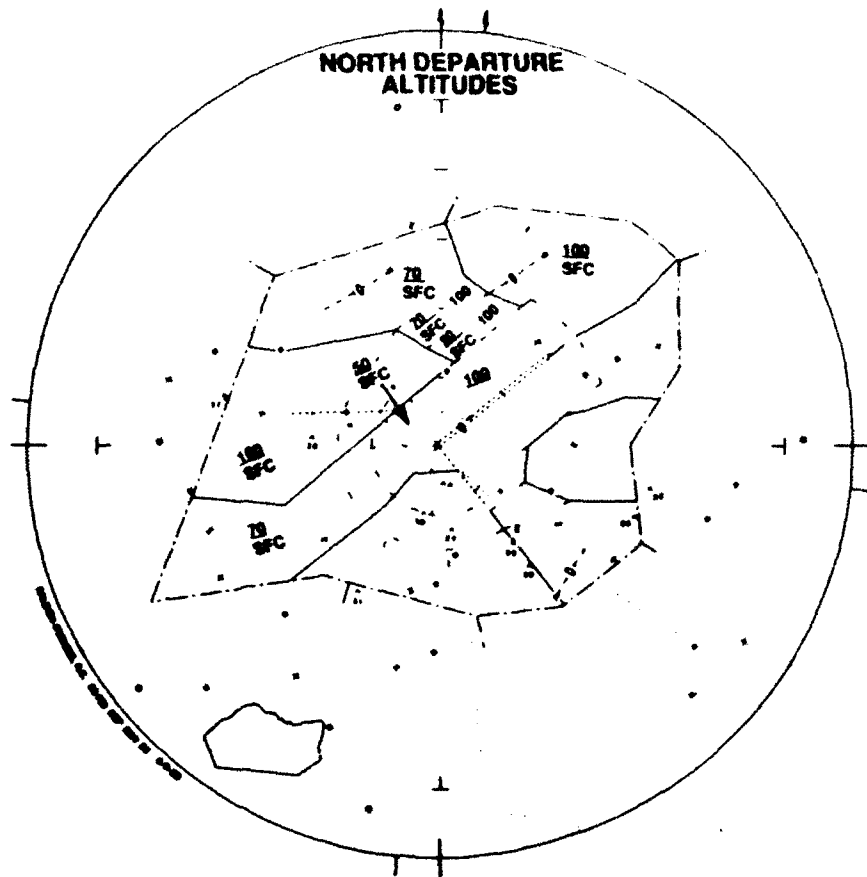
The North Departure Controller radar
identifies aircraft immediately
after departing from Raleigh-Durham
Runway 23R. Then climbs and vectors
the aircraft toward one of two
departure gates. As the aircraft
nears another facilities airspace
the controller transfer control of
the flight and changes the pilots
frequency.



**NORTH DEPARTURES**

A-2

**SOUTH DEPARTURE ALTITUDES**
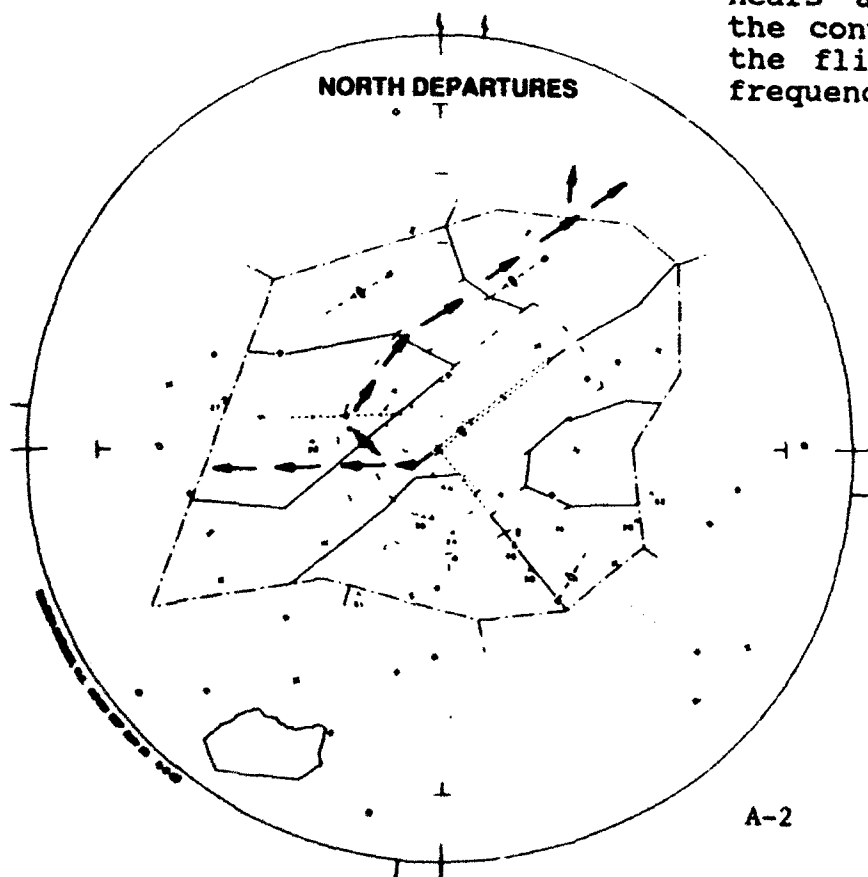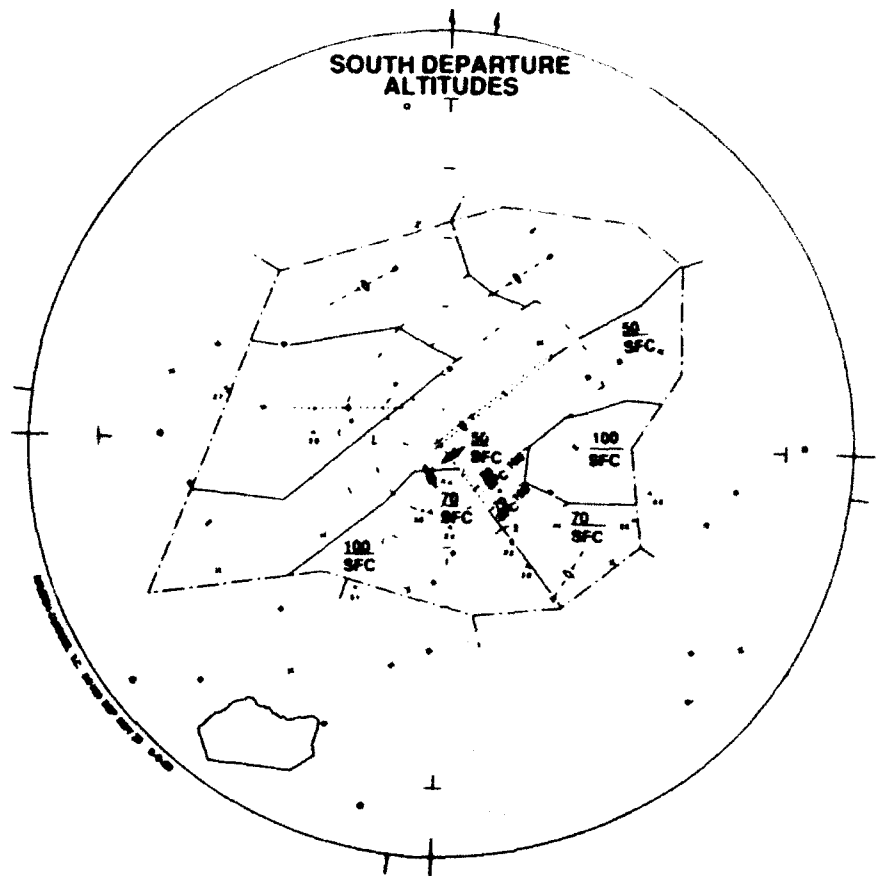


The South Departure Controller radar identifies aircraft immediately after departing from Raleigh-Durham Runway 23L. Then climbs and vectors the aircraft toward one of two departure gates. As the aircraft nears another facilities airspace the controller transfer control of the flight and changes the pilots frequency.

**SOUTH DEPARTURES**



A-3
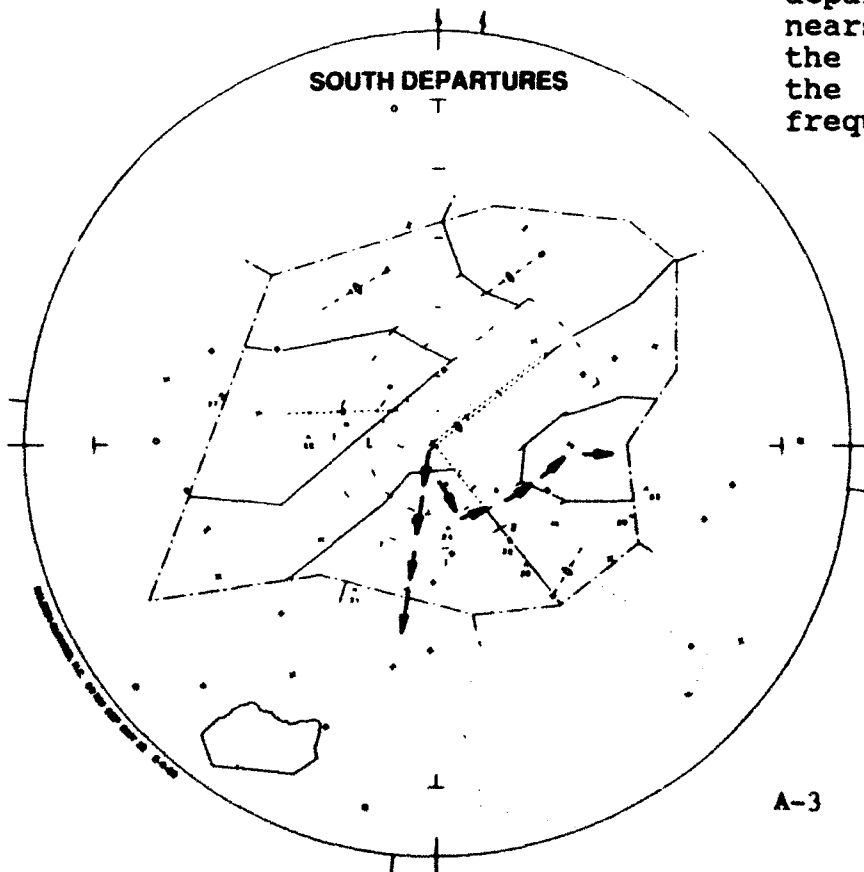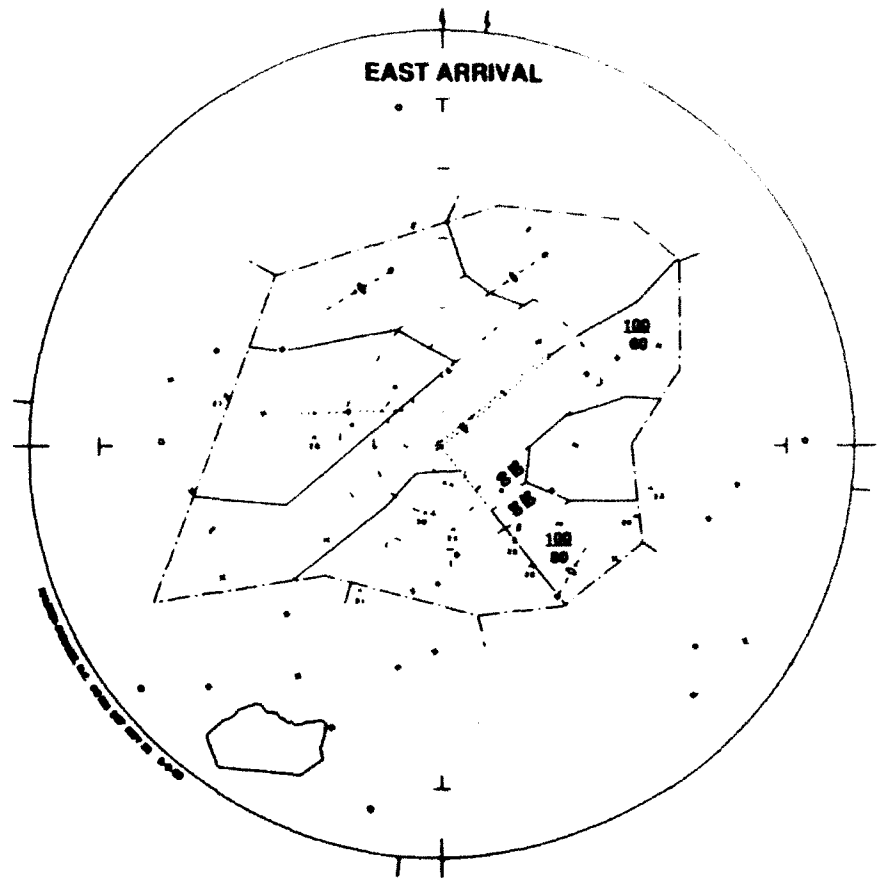
EAST ARRIVAL

The East Controller accepts arrival
and transgressing flights from the
South and East of Raleigh-Durham
airspace. The flights from two
arrival areas are sequenced together
and handed of to the East Final
controller who provides the flight
instructions for landing.



EAST ARRIVALS

A-4

WEST ARRIVAL
ALTITUDES
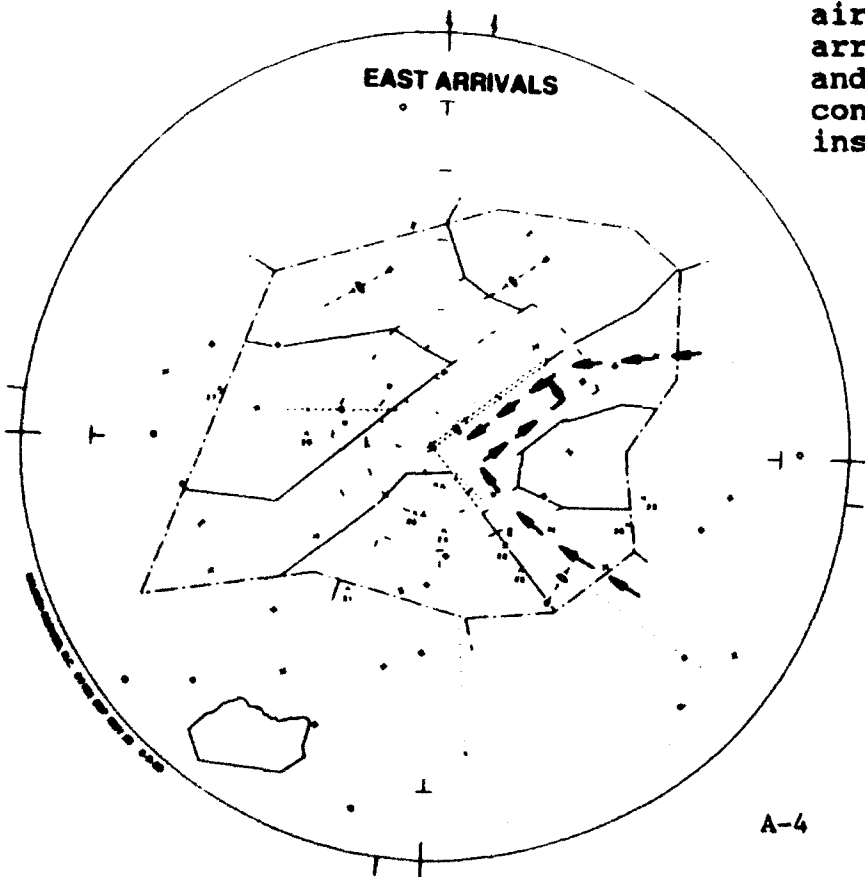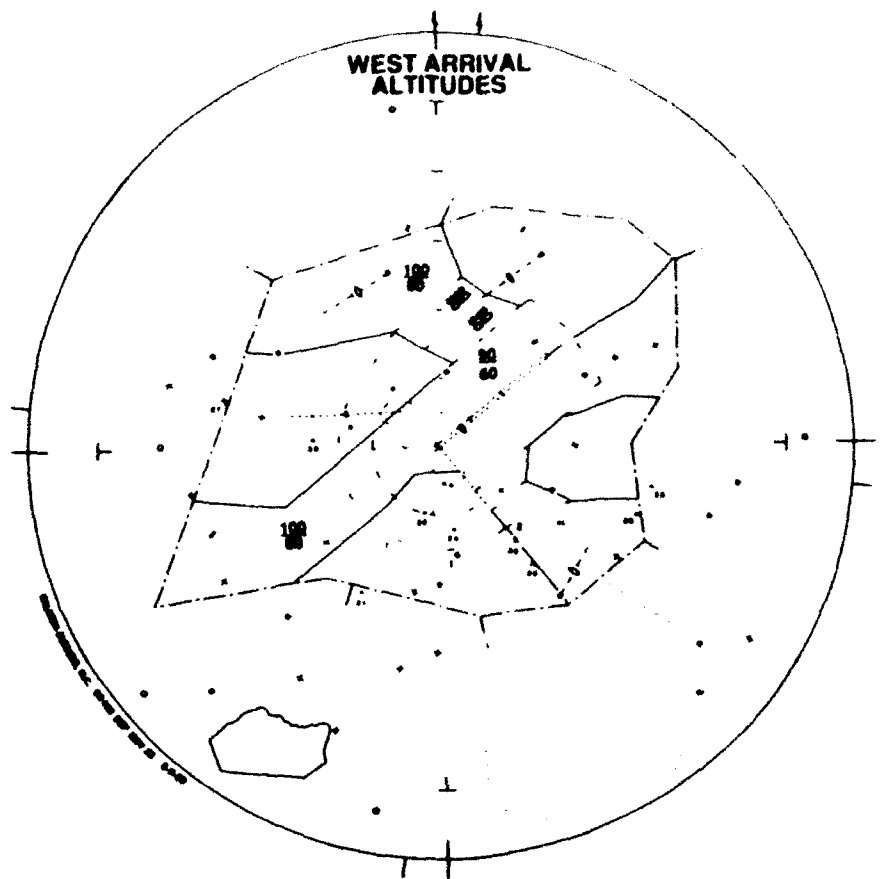


The West Controller accepts arrival
and transgressing flights from the
North and West of Raleigh-Durham
airspace. The flights from two
arrival areas are sequenced together
and handed off to the West Final
controller who provides the flight
instructions for landing.

WEST ARRIVALS

A-5

**EAST & WEST FINAL ALTITUDES**
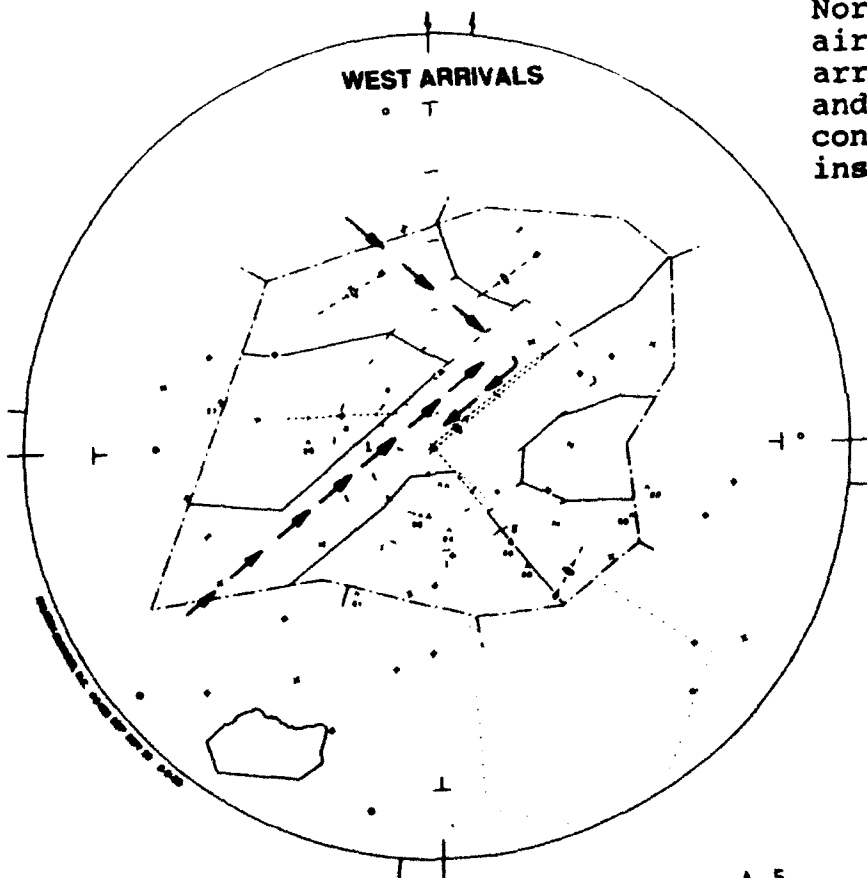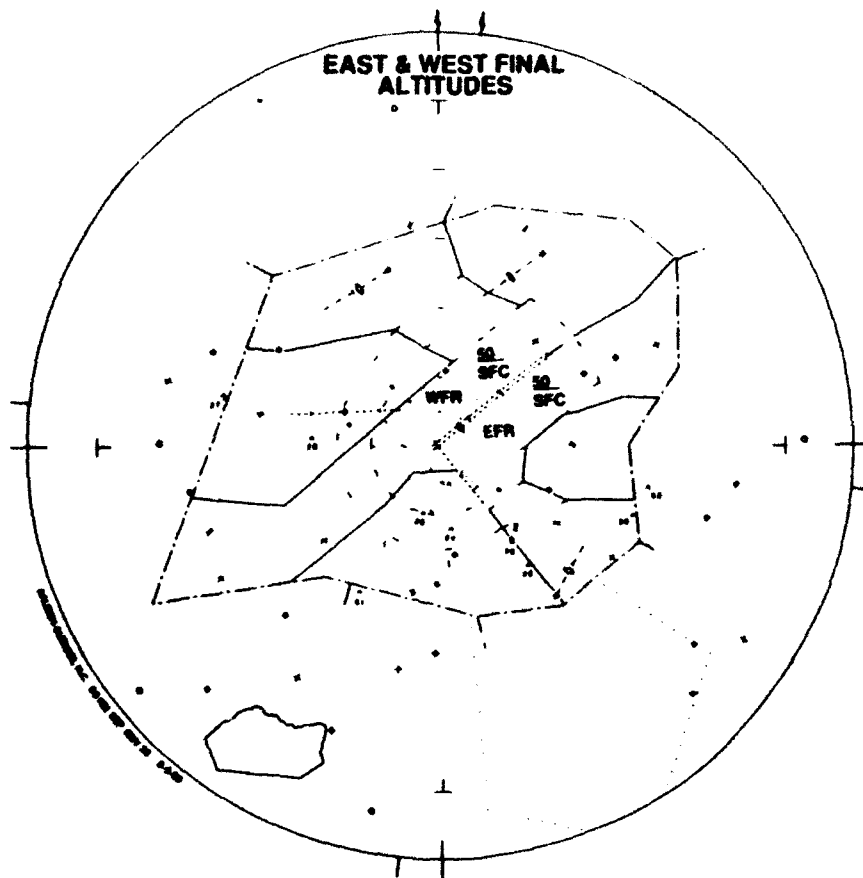
The East and West Final controllers provide sequencing adjustment and approach clearances for multiple aircraft landing at Raleigh-Durham.

# APPENDIX B

## DATA LINK SERVICE DESCRIPTIONS
## DESIGN REVIEW MATERIALS

CONTROLLER EVALUATION OF
INITIAL DATA LINK TERMINAL SERVICES

ARTS IIIA

DESIGN REVIEW BOOKLET

MINI STUDY 3

This booklet contains a series of questions which will permit you
to independently review and evaluate the designs of the terminal
services as modified by the results of the last study and
currently implemented in the ARTS IIIA section of the Data Link
Test Bed.

Please answer all questions in the booklet and carefully record
any recommendations for design changes.  Explain your reasons for
suggesting these changes.

Remember, your main task is to concentrate on completing the
booklet.  We are doing the review in the Test Bed so that you can
examine the service designs as you work on the booklet.  During
this session it is not important to maintain precise control of
the air traffic in the scenario.

REVIEWER NAME _____

## INSTRUCTIONS

This review is divided into eight sections. Each of the first seven sections begins with a description of the relevant features or services that will be addressed by the following questions. Please read these descriptions carefully and use them along with your observations in the Test Bed to answer the questions.

During this session you should switch control positions between scenarios so that you will be able to evaluate each of the services.

## NOTE

In the following service descriptions:

- The SLEW command should be interpreted as the action sequence of acquiring the target with the trackball and pressing the trackball enter key.

- The ENTER command should be interpreted as pressing the keyboard ENTER key.

- Data as shown in a display or entered on the keyboard are presented in quotation marks. The quotation marks are not part of the display or entry.

# GENERAL DATA LINK FEATURES

- Data Block Equipage and Eligibility Symbols

The terminal Data Link design uses graphic symbols in the first position of the first line of the data block to indicate whether an aircraft is equipped with a functioning Data Link system and whether the control position displaying the track is eligible to communicate with the aircraft. No symbol in the data block identifies an aircraft that does not have Data Link capability. A "plus sign" (+) indicates that the aircraft is equipped to communicate using Data Link, but that the control position is not eligible to communicate with it. An asterisk (*) identifies an aircraft that has Data Link capability and indicates that the control position is eligible to communicate with it using Data Link.

- Data Link Key

Several functions associated with the Data Link system require the controller to precede a command entry with a special keystroke. In the current design, this Data Link (D/L) key is F9 on the ARTS IIIA keyboard.

- One Transaction Per Aircraft

For all services, only one Data Link transaction per aircraft may be in progress at a time -- Except in the case of a "held" TOC, the controller may not uplink a new message until the previous message has been wilcoed or a transaction that has failed has been cleared from the data block display.

- Transaction Delete Command

An ongoing Data Link transaction, or one that has resulted in a failure, can be deleted by pressing the D/L key and a SLEW action. This input clears the data block and status list displays for the transaction and permits the system to accept the next message to the aircraft. The input does not recall the message or prevent it from reaching the aircraft. No provision for attempting to recall a message that has been sent is included in the design.

- Message Resend Command

If a Data Link transaction is not completed because of a technical failure (NAK), the controller can resend the message by a SLEW action. The system will not accept the resend input if the response from the pilot is "UNABLE" (UNA).

- No Response Lock Out After Time out

In the current design, the data block and status list display a timeout message if the pilot fails to respond to a delivered message within 40 seconds. This display is an alerting message for the controller, and does not prevent the system from accepting a subsequent "WILCO" or "UNABLE" response. The transaction will remain open until one of these messages is received or the controller enters the transaction delete command.

REVIEW QUESTIONS:

1. Does the description accurately represent the general operational features of the system that you observed in the Test Bed?

    _____    YES, THE DESCRIPTION IS CORRECT

    _____    NO, IT DOESN'T MATCH

              Describe those aspects of the description that did not match your observations --

2. In the current design, the transaction delete command clears the status displays and makes it possible to send another message to the aircraft. No recall attempt (formerly F9X) is possible. What communication procedures should be followed when a transaction is deleted?

3. In the current design, the message resend command can be used after a Data Link transmission failure (NAK). Should the resend be a legal command in the operational system if a NAK does not guarantee that the message failed to reach the pilot?

4. The "time out" (TIM / T) display is presented if the pilot
   fails to wilco or unable a message within 40 seconds.  In the
   current design, this display is an alert to the controller,
   and does not prevent the system from receiving a later pilot
   response.  Assuming that normal total transaction times are
   shorter than 20 seconds, would the alert be more effective if
   it was displayed at an earlier time?  If yes, when should it
   be displayed?

5. What should be done to improve the general operational
   features of the Data Link services discussed in this section?
   Include any changes suggested by your answers to questions
   2. - 4. above.

   _____   THE CURRENT IMPLEMENTATION IS ACCEPTABLE -- NO
              CHANGES ARE DESIRABLE OR NEEDED

   _____   THE CURRENT IMPLEMENTATION IS ACCEPTABLE -- NO
              CHANGES ARE NEEDED, BUT THE FOLLOWING WOULD BE
              DESIRABLE: (describe)

   _____   THE CURRENT IMPLEMENTATION IS UNACCEPTABLE --
              THE FOLLOWING CHANGES MUST BE MADE:

# STATUS LIST AND DATA BLOCK
# TRANSACTION STATUS DISPLAYS

- Function

The status list contains information on the status of up to 15 ongoing Data Link transactions per sector. Each of the lines displays the content and status of a single transaction. The display on the third line of the data block also provides status and content data for an ongoing transaction.

- Status List and Data Block Format

Each line on the status list has three data fields displaying the Aircraft ID, the message content, and the current status of the transaction (e.g. "AAL123 TI*A SNT").

The third line of the data block presents the message content and the current status of the transaction (e.g. A120 D).

- Status Messages

The abbreviations used for the status messages in the status list are "SNT" (message sent), "DLV" (message delivered to aircraft), WIL (pilot wilco received), "NAK" (failure of system to successfully deliver message to aircraft), "UNA" (pilot unable to comply with message), and TIM (pilot failed to respond to a delivered message within 40 seconds).

The third line of the data block does not display the message sent or Wilco status. The single letters "D", "N", "U" and "T" are used to indicate Delivered, NAK, Unable, and Time out.

- Status List and Data Block TI and MT Message Content

The content of a Terminal Information (TI) message represented in the status list and in the third line of the data block is denoted by displaying the acronym "TI", an asterisk, and the alphabetic letter message identifier associated with the message in the TI list (e.g. "TI*A").

The content of a Menu Text message represented in the status list and the data block is represented by a shorthand description of the clearance sent. Altitude, heading, and velocity change clearances are abbreviated by "A", "H", and "V", respectively. The letter is followed by a 3-digit number indicating the altitude level or compass heading, or a 2-digit number indicating speed (V) in hundreds of knots (e.g. "A120H150V15"). If a left or right turn direction was selected when sending a heading clearance, the "H" is replaced by an "L" or "R".

- Displays on Receipt of Wilco

When an aircraft downlinks a Wilco to a transaction contained in the status list, "WIL" is displayed for 8 seconds, after which all transaction information is deleted from the list. The Wilco response is indicated in the data block by immediately clearing all data on the third line.

- "Failure" Alerting Displays

If a transaction results in a NAK, Unable, or Time Out, the message content display and the single letter indicator ("N", "U" or "T") shown in the data block flash to alert the controller. The corresponding messages in the status list ("NAK", "UNA", "TIM") do not flash.

- Displays on Resend

If the controller resends a message that has failed, the failed message is cleared from the status list and a new status entry appears when the message is sent.

- Quick-Look Data Block Display

If a controller quick looks a Data Link equipped aircraft that is under the control of another position, the third line of the data block will only be displayed to the Data Link eligible controller.

- Inputs to Display/Suppress Status List

The status list is displayed by pressing the D/L key (F9), typing "S" and ENTER. When the list is displayed, the identical input sequence will suppress the list.

- Inputs to Move the Status List

The status list can be moved to any position on the display by pressing the F8 key, typing "S" and SLEW.

---

REVIEW QUESTIONS:

1. Does the description accurately represent the design and operation of the Status List and Data Block transaction status displays that you examined in the Test Bed?

    _____   YES, THE DESCRIPTION IS CORRECT

    _____   NO, IT DOESN'T MATCH

    Describe those aspects of the description that did not match your observations --

2. Do the abbreviated status messages used in the Status List (SNT, DLV, WIL, NAK, UNA, TIM) and Data Block (D, N, U, T) provide sufficient information?  Are they easy to interpret?

3. As suggested during the last study, the Data Block display (and the Status List) now gives more direct information about the content of a Menu Text transaction in progress.  Should the shorthand abbreviation of heading, altitude, and speed clearances be included in the final design, or would the item identifier number be sufficient?  Why?

4. Are the item letter identifier displays in the Data Block and Status List adequate for Terminal Information messages?

5. Does flashing the U, N, and T in the Data Block provide an adequate controller alert for these "failure" conditions?

6. Is it useful to display "WIL" in the Status list for 8 seconds after the wilco is received from the aircraft? Why or why not?

7. What should be done to improve the design of the Transaction Status Displays? Include any changes suggested by your answers to questions 2. - 6. above.

_____ THE CURRENT IMPLEMENTATION IS ACCEPTABLE -- NO CHANGES ARE DESIRABLE OR NEEDED

_____ THE CURRENT IMPLEMENTATION IS ACCEPTABLE -- NO CHANGES ARE NEEDED, BUT THE FOLLOWING WOULD BE DESIRABLE: (describe)

_____ THE CURRENT IMPLEMENTATION IS UNACCEPTABLE -- THE FOLLOWING CHANGES MUST BE MADE:

# HISTORY LIST

- Function

The history list provides a record of the last 3 Data Link messages wilcoed by an aircraft. The first line of the list contains the ACID of the subject aircraft, while the remaining lines display the messages received. Messages are automatically sent to the history list when the wilco is received.

- Message Content Display

In general, the content of messages represented in the history list is displayed with minimal use of abbreviations (e.g. FLY HDG 150). However, when a single message contains multiple menu text clearances or a terminal information message combined with a menu text clearance, alternate representations are used to conserve display space. If a TI message is combined with an MT message, the content of the clearance portion of the message is abbreviated using the shorthand form used in the status list and data block displays. In this case, the TI portion of the message is displayed on one line and the MT clearance is presented on the following line preceded by three periods to indicate that the clearance was appended to the TI (e.g. "TI message"
         "...A060")

When multiple MT clearances are included in a message they are displayed in the shorthand form on a single line of the history list separated by spaces (e.g. "H150 A060 V15").

- Message Order

The messages are listed in reverse chronological order of receipt, with the most recently received message appearing at the bottom of the list. The list scrolls up as new messages are received.

- Inputs to Display History List

The history list for an aircraft can be viewed by entering "HL" and SLEW.

- Location of History List

The history list replaces the status list. The history list remains in this position for 8 seconds after it is selected and is then replaced by the status list. Alternatively, reentering the "HL" SLEW command for the same aircraft will manually remove the history list.

---

REVIEW QUESTIONS:

1. Does the description accurately represent the design and operation of the History List that you examined in the Test Bed?

        _____   YES, THE DESCRIPTION IS CORRECT

        _____   NO, IT DOESN'T MATCH

                  Describe those aspects of the description that did not match your observations --

2. Will 3 messages for each aircraft provide a sufficient record of past transactions in the History List? If not, how many will be needed?

3. In the current design, abbreviated text is used for displaying TI and MT transactions when a single message was sent. To deal with space limitations, the system reverts to displaying the MT message(s) in the shorthand form when a TI and an MT, or multiple MT clearances were sent in a single message -- Is this preferred, or should MT messages be presented consistently in the shorthand form for all situations?

4. In the current design, the History List shares locations with the Status List. Is this preferable to overlaying the MT/TI list as in earlier designs?

5. Is the 8 second display time (with an ability to suppress the display earlier) adequate for the History List?

6. What should be done to improve the design of the History List? Include any changes suggested by your answers to questions 2. - 5. above.

_____ THE CURRENT IMPLEMENTATION IS ACCEPTABLE -- NO CHANGES ARE DESIRABLE OR NEEDED

_____ THE CURRENT IMPLEMENTATION IS ACCEPTABLE -- NO CHANGES ARE NEEDED, BUT THE FOLLOWING WOULD BE DESIRABLE: (describe)

_____ THE CURRENT IMPLEMENTATION IS UNACCEPTABLE -- THE FOLLOWING CHANGES MUST BE MADE:

# INITIAL CONTACT (IC)

## SERVICE DESCRIPTION:

- Initiation of IC

The IC is initiated when the aircraft pilot responds with a WILCO message to a preceding transfer of communication. The aircraft's assigned altitude is appended to the WILCO downlink response, and this value is sent via interfacility or intrafacility data channels to the receiving control position.

If the aircraft fails to append the assigned altitude to the TOC wilco, the system automatically sends an altitude request (AR) message to the aircraft. The ongoing status of this transaction is displayed in the receiving controller's status list and data block. An AR is also automatically sent to departing aircraft in order to initiate the IC for first contact.

- Display on Downlink of Assigned Altitude

When the aircraft downlinks its assigned altitude with the wilco to the TOC or in response to an AR, the third line of the data block displays the characters "IC" followed by the 3-digit altitude value (e.g. "IC 110"). The third line of the Data Block flashes to capture the controller's attention and signal a required response.

- Response to an IC Downlink

The controller response may be a TI message, initiation of a transfer of communication, one or more menu text messages, or a combination of a TI message and an MT message. Initiation of the uplink immediately deletes the "IC" display in the third line of the data block.

---

REVIEW QUESTIONS:

1. Does the description accurately represent the design and operation of the Initial Contact service that you examined in the Test Bed?

       _____    YES, THE DESCRIPTION IS CORRECT

       _____    NO, IT DOESN'T MATCH

                Describe those aspects of the description that did not match your observations --

2. The major change to the IC included in this implementation was made to eliminate the delay associated with the uplinked altitude request and IC downlink. In the current design, the assigned altitude is downlinked with the Wilco to the Transfer of Communication. Is this change acceptable? Do you foresee any potential operational problems with the procedure?

3. The altitude request (AR) uplink is used in the present design to deal with first contact departures and aircraft that do not append the assigned altitude to the TOC wilco. Is this procedure acceptable? Do you foresee any potential operational problems?

4. Is the flashing IC display in the Data Block adequate to capture the controller's attention when the altitude is downlinked?

5. Are the TI, MT, and combination uplink options sufficient to cover all operational requirements for responses to the IC?

6. What should be done to improve the design of the Initial Contact service ?  Include any changes suggested by your answers to questions 2. - 5. above.

    _____ THE CURRENT IMPLEMENTATION IS ACCEPTABLE -- NO CHANGES ARE DESIRABLE OR NEEDED

    _____ THE CURRENT IMPLEMENTATION IS ACCEPTABLE -- NO CHANGES ARE NEEDED, BUT THE FOLLOWING WOULD BE DESIRABLE: (describe)

    _____ THE CURRENT IMPLEMENTATION IS UNACCEPTABLE -- THE FOLLOWING CHANGES MUST BE MADE:

## TERMINAL INFORMATION SERVICE (TI)

**SERVICE DESCRIPTION:**

- Initiation of TI

A message in the TI list can be sent at any time through a controller input action. When used immediately after receiving an initial contact message from an aircraft ("IC" and an altitude value displayed in the third line of the data block) a slew input can be used to send a commonly-used default TI message.

- TI List Display

TI messages are selected from a list display with the header "TI" at the top and containing four optional messages. Each message is preceded by an identifier letter (A - D). The message appearing on the first line (regardless of its identifier letter) is the default message. Each of the messages can be up to 40 characters long.

- Inputs to Change Default Message

The default message can be changed by pressing the D/L key followed by "D", the identifying letter of the new item desired (A to D), and ENTER. This action will move the selected item to the first line of the list and rearrange the remaining items in alphabetic order of their identifier letters. Items always retain their original identifier letters regardless of the item designated as the default message. Changing the default message automatically restores any suppressed items to the TI list (see suppressing individual TI messages below).

- Inputs to Reposition TI List

The TI list can be moved independently to any position on the ARTS display by pressing the F8 key, typing "T" and SLEW to position the list.

- Inputs to Suppress / Retrieve TI List

The entire TI list can be removed from the ARTS display by pressing the D/L key, typing "T" and ENTER. Repeating this sequence will retrieve the list.

- Suppressing Display of Individual TI Messages

If desired, fewer than 4 TI messages can be displayed in the list. Pressing the D/L key followed by the item identifier letter and ENTER removes the selected item from the list display. All other items maintain their original letter identifiers, and the suppressed item remains available for uplink by the normal data entries. Items can be retrieved to the list display by repeating the D/L key - item identifier entry. If all items in the list are individually suppressed, the "TI" header remains on the display to indicate the suppressed list location and to remind the controller that restoring the list will require individual entries rather than the entry used to retrieve the entire list if it had been suppressed using the F9T entry.

Changing the default message in the TI list will automatically restore all individually suppressed items to the list.


- **Inputs to Send Default TI After IC**

When a successful initial contact has been completed and the third line of the data block displays "IC" followed by an altitude value, the default TI message may be uplinked by a SLEW action.


- **Inputs to Send TI Messages at Any Time**

Messages can be uplinked at any time by typing "T", the message identifier letter from the TI list (e.g. "B") and SLEW.


- **Displays on TI Uplink**

If a TI message is sent when "IC" and an altitude value are shown in the third line of the data block, the entry deletes the "IC" and altitude, and replaces it with "TI*" followed by the message letter selected from the list for uplink. The status list entry displays the identical message.


- **Displays After Pilot WILCO**

Upon receipt of a downlinked WILCO response from the aircraft, the "TI"/message letter display in the third line of the data block is deleted. WIL is displayed in the status list entry for 8 seconds before the entry is deleted.


- **Combining TI with an MT Message**

Any TI message can be sent together with one MT message by typing "T" and the TI message letter desired prior to the Menu Text entry (e.g. "TDM4"). The multiple MT message displayed on line 9 of the MT list cannot be combined with a TI message. The default TI message can be sent with a Menu Text message without specifying the TI message number (e.g. "TM4") if the IC message is flashing in the Data Block.


- **Changing the Content of TI Messages**

The content of any of the four TI messages can be changed by pressing the D/L key, "T", and the identifier letter of the message to be changed. These entries are followed by a space, the desired text message, and ENTER (e.g. "F9TB text messageENTER"). The text message may be up to 40 characters long.

---

REVIEW QUESTIONS

1. Does the description accurately represent the design and
   operation of the Terminal Information service that you
   examined in the Test Bed?

   _____    YES, THE DESCRIPTION IS CORRECT

   _____    NO, IT DOESN'T MATCH

             Describe those aspects of the description that
             did not match your observations --

2. In the current design, each of the four TI messages can be
   displayed with a maximum of 40 characters.  Will these
   increased message lengths be sufficient for operational
   application?

3. The TI message identifiers have been changed to alphabetic
   letters rather than numerals for the current implementation.
   Does this change adversely affect the ease with which messages
   can be selected from the list or the interpretation of status
   displays?  If so, in what way?

4. The TI list can now be suppressed and moved independently from
   the MT list.  Is this feature useful?  Why or why not?

5. It is now possible to suppress individual items on the TI list. Is this feature useful? Why or why not?

6. Does the design offer sufficient flexibility for combining TI and MT messages?

7. What should be done to improve the design of the Terminal Information service ? Include any changes suggested by your answers to questions 2. - 5. above.

    _____    THE CURRENT IMPLEMENTATION IS ACCEPTABLE -- NO CHANGES ARE DESIRABLE OR NEEDED

    _____    THE CURRENT IMPLEMENTATION IS ACCEPTABLE -- NO CHANGES ARE NEEDED, BUT THE FOLLOWING WOULD BE DESIRABLE: (describe)

    _____    THE CURRENT IMPLEMENTATION IS UNACCEPTABLE -- THE FOLLOWING CHANGES MUST BE MADE:

# TRANSFER OF COMMUNICATIONS (TOC)

## SERVICE DESCRIPTION:

- Initiation of TOC

The TOC message containing a new radio frequency for an aircraft is automatically prepared when the receiving controller accepts a sector hand off.

- TOC Mode Display

TOC can be set to operate in either an automatic send or manual send mode. The active TOC mode is displayed in the Systems Data Area (SDA). "TC HOLD" is displayed when the system is in the manual send mode and "TC SEND" is displayed when the system is in the automatic send mode. When the ARTS program is started, TOC is in the manual or hold mode. Pressing the D/L key, "TH" and ENTER will change TOC to the automatic mode and cause the mode display to change to "TC SEND". Repeating the same entry will switch the mode back to "TC HOLD"

- Inputs to Send TOC - TC SEND Mode

If in the TC SEND mode, the TOC is automatically uplinked upon acceptance of the hand off when the sending controller completes the normal keyboard sequence for hand off initiation (HANDOFF key (F5), the receiving sector's Controller Symbol, and SLEW). Any other currently acceptable ARTS input sequence normally used to initiate a hand off will result in the same automatic uplink of TOC (e.g. F5-ACID-Controller Symbol- ENTER).

- Display on TC SEND TOC Uplink

"TC" is displayed in the third line of the data block and in the status list when the TOC message is uplinked.

- Inputs to Hold a Message When in TC SEND Mode

When in the TC SEND Mode, the TOC can be held for delayed uplink by adding an "H" prior to the SLEW entry for the Handoff (i.e. "F5, Controller Symbol, H, SLEW"). The system will revert to the TC SEND mode for succeeding TOCs unless the mode is changed or the "H" is again added to the handoff entry.

- Inputs to Send TOC - TC HOLD Mode

When in the TC HOLD mode, the controller may initiate the sector hand off but reserve communications eligibility until a later time by completing the normal keyboard sequence for hand off initiation (HANDOFF key (F5), the receiving sector's Controller Symbol, and SLEW). Any other currently acceptable ARTS input sequence normally used to initiate a hand off will result in the same held status of TOC (e.g. F5-ACID-Controller Symbol- ENTER). The TOC can then be sent manually by a SLEW action.

**- Display on Manual (TC HOLD) Uplink**

"TC H" is displayed in the third line of the sending sector's data block when a handoff has been completed in the hold mode. "SNT" and succeeding transaction states are displayed in the status lists of both the sending and receiving sectors when the SLEW is completed to manually send the TOC.

**- Inputs to Automatically Send TOC When in TC HOLD mode**

When in the TC HOLD Mode, the TOC can be sent automatically upon handoff acceptance by adding an "S" prior to the SLEW entry for the hand off (i.e. F5, Controller Symbol, S, SLEW). The system will revert to the TC HOLD mode for succeeding TOCs unless the mode is changed or the "S" is again added to the hand off entry.

**- Display After Pilot WILCO**

In both automatic and manual procedures the "TC" display in the third line of the data block is deleted when the aircraft downlinks a WILCO response. The status list entry will display "WIL" for 8 seconds after receipt of the wilco, and then will be deleted.

**- Sending Other Messages When a TOC is in Held Status**

An MT or TI message can be sent to the aircraft while a TOC is in the held status. Sending the new message will replace the "TC H" display in the data block with the type, identifier and status of the TI or MT message. When the message is wilcoed, the "TC H" reappears in the data block.

**- Offering a Hand Off While a Data Link Transaction is in Progress**

If a Data Link transaction is in progress when the sending controller wishes to hand off to another sector, the normal hand off entries will be accepted by the ARTS computer, and the hand off can be accepted by the receiving controller. The ongoing message status will continue to be displayed in the data block until it is wilcoed or until the controller enters the message delete command. The TOC message will then be automatically sent if 1) the handoff has been accepted and 2) the system is set to the TC SEND mode or the controller added the "S" keystroke to the hand off entry in the TC HOLD Mode.

If the handoff is accepted and the system is in the TC HOLD mode or the controller added the "H" keystroke to the hand off entry in the TC SEND mode, the wilco or deletion of the prior transaction will cause the TC H display to appear in the data block, and the TOC will be sent when the SLEW is completed. In all cases, the receiving controller's status list (but not data block) will show the TOC status when the TOC message is sent.

**- Inputs to Acquire Data Link Eligibility**

The controller may acquire ("steal") eligibility for Data Link communications by pressing the D/L key, typing the letters "OK" and a SLEW action. This action also sends a TOC message to the aircraft.

REVIEW QUESTIONS:

1. Does the description accurately represent the design and operation of the Transfer of Communication service that you examined in the Test Bed?

    _____    YES, THE DESCRIPTION IS CORRECT

    _____    NO, IT DOESN'T MATCH

            Describe those aspects of the description that did not match your observations --

2. The active mode for the TOC is now displayed in the Systems Data Area and defaults to "TC HOLD" on system start-up. Are these changes preferable to the earlier approach of displaying the mode at the top of the status list and defaulting to "TC" SEND"? Would some other approach be better?

3. In the current design, it is possible to offer a hand off and have it accepted by the receiving controller while a Data Link transaction is in progress. Are the resulting Data Block display and sequence of events for accomplishing the TOC after the completion of the prior transaction acceptable? If not, why?

4. The receiving sector's Data Block no longer displays information about the TOC transaction being completed by the sending controller. Is this change desirable? Why or why not?

5. What should be done to improve the design of the Transfer of Communication service?  Include any changes suggested by your answers to questions 2. - 4. above.

_____ THE CURRENT IMPLEMENTATION IS ACCEPTABLE -- NO CHANGES ARE DESIRABLE OR NEEDED

_____ THE CURRENT IMPLEMENTATION IS ACCEPTABLE -- NO CHANGES ARE NEEDED, BUT THE FOLLOWING WOULD BE DESIRABLE: (describe)

_____ THE CURRENT IMPLEMENTATION IS UNACCEPTABLE -- THE FOLLOWING CHANGES MUST BE MADE:

# MENU TEXT (MT)

## SERVICE DESCRIPTION:

### - Function

The MT service permits the controller to uplink speed, heading and altitude clearances by selecting the required messages from a predefined menu or by composing clearances not contained in the menu.

### - MT List Display

Available MT clearances are displayed in a list containing 9 lines. Each menu item is displayed on a single line preceded by an identifier number (1-9). Messages are selected using the identifier numbers.

The first 8 lines are dedicated to specific clearance types. Lines 1, 2 and 3 are for heading clearances and are preceded by the header "HDG". Lines 4, 5 and 6 are reserved for altitudes and are preceded by the header "ALT". Lines 7 and 8 are for speed control and are preceded by the header "VEL". Line 9 is preceded by the header "MULT", and is used for a multiple entry composed of any two or three items contained in lines 1 to 8. Only one of each clearance type may be entered on line 9.

### - MT List Item Content

The content of each of the three clearance types is highly structured, and automation is used to produce a complete message from the structured data. In each case, clearances are displayed in the menu as a numerical value followed by "DEG", "FT", or "KTS". The direction of an altitude change (descend or climb) is added by the automation when the message is sent by comparing the aircraft's current altitude with the message data. The "increase" or "decrease" commands are added to a velocity message in a similar manner. Heading clearances are sent as "Fly Heading.." unless a special command is added to the menu selection as described below. The line 9 multiple clearance is displayed by the relevant item identifier numbers separated by slashes (e.g. "1/5/8").

### - Inputs to Send a MT Message

A single MT item can be uplinked by typing "M" followed by the menu item identifier number, and a SLEW action.

### - Controlling the Direction of a Turn in a Heading Clearance

The specific direction of a turn can be included in a heading message contained in the menu by typing an "L" or "R" after the menu identifier number (e.g. "M1R SLEW).

### - Inputs to Reposition MT List

The position of the MT list on the ARTS display can be independently changed by pressing the F8 key, typing "M", and completing a SLEW action to move the list.

- Inputs to Suppress / Retrieve MT List

The entire MT list can be removed from the display by pressing the D/L key and typing "M" and ENTER. The list is retrieved using the same sequence of key strokes.


- Suppressing Display of Individual MT Messages

If desired, fewer than 9 MT messages can be displayed in the list. Pressing the D/L key followed by the item identifier number and ENTER removes the selected item from the list display. All other items maintain their original number identifiers, and the suppressed item remains available for uplink by the normal data entries. Items can be retrieved to the list display by repeating the D/L key - item identifier entry. If all items in a particular category (HDG, ALT, VEL, MULT) are suppressed, the category header also will be suppressed. If all items in the list are individually suppressed, the "MT" header remains on the display to indicate the suppressed list location and to remind the controller that restoring the list will require individual entries rather than the entry used to retrieve the entire list if it had been suppressed using the F9M entry.


- Inputs to Send Multiple MT Messages

Up to three MT menu items can be sent in a single uplink by inserting spaces between the item numbers. (e.g. M1 4 8 SLEW would send menu items 1, 4 and 8). Item 9 cannot be combined with other items. The software will not permit attempts to send more than one of each clearance type (altitude, heading or altitude) in a multiple menu uplink.


- Bypassing the Menu

A heading (H), altitude (A) or velocity (V) not contained in the menu can be uplinked by pressing the D/L key, typing "H", "A" or "V" followed by the numeric value of the clearance and SLEW. One of each clearance type also can be combined in a single uplink in any order (e.g. "F9H230A030"). The third line of the data block and the status list entry display the clearance letters, and the numerical values entered (e.g."A 110") until the message is wilcoed. The direction of a turn for a heading clearance can be controlled by substituting "L" or "R" for "H" in the data entry.


- Inputs to Send an MT Message Combined with TI

A TI message can be sent in combination with one MT item by adding "T" and the desired TI message number prior to the first MT input (e.g. TDM3 SLEW would send TI message D and menu item 3). The default TI message can be combined with an MT message without specifying the default's identifier number (e.g. TM3 SLEW) if the IC message is flashing in the Data Block.


- Displays on MT Uplink

When an MT or By-pass uplink is initiated, the third line of the data block and the associated status list line displays a shorthand abbreviation of the message content (e.g. "H230A030")

**- Displays After Pilot WILCO**

A downlinked WILCO to an MT message or group of messages deletes the data in the third line of the data block and causes "WIL" to be displayed in the status list for 8 seconds.

**- Modifying Numeric Values in Menu Items**

The numeric value of a heading, speed or altitude clearance can be changed by pressing the D/L key, typing M and the one-digit identifier number of the menu item to be changed, typing the new numeric value and pressing the ENTER key (e.g. "F9M3060").

If a SLEW action is substituted for the keyboard ENTER, the menu item will be changed AND the message will be uplinked to the slewed aircraft. For heading clearances, if "L" or "R" is appended to the entry prior to the SLEW (e.g. "F9M3060L") the directional turn clearance will be uplinked (e.g. "Turn Left Heading 060"), but the modified menu item will contain the generic heading message for future use (e.g. "Fly Heading 060"). In all cases, modified values will stay in the MT list entries until they are changed again or the program is restarted.

**- Creating/Modifying Line 9 Combination Clearance**

Line 9 permits the combination of up to three clearances shown in lines 1 to 8. This entry is created or modified by pressing the D/L key, typing "M9", the identifier numbers for two or three of entries 1 to 8 and ENTER. If a SLEW action is substituted for ENTER, the combined clearance will be entered in the list and simultaneously sent to the designated aircraft.

REVIEW QUESTIONS:

1. Does the description accurately represent the design and operation of the Menu Text service that you exam¹ned in the Test Bed?

     _____    YES, THE DESCRIPTION IS CORRECT

     _____    NO, IT DOESN'T MATCH

             Describe those aspects of the description that did not match your observations --

2. The letter used to prefix speed clearances composed with the Menu Bypass feature was changed from "S" to "V" (velocity) in order to locate all three prefix letters ("A", "H", and "V") in the same column on the ARTS keyboard. Is this change acceptable? Will it simplify the task of composing bypass messages?

3. The current menu design has added headers (HDG, ALT, VEL, MULT) to each category of clearance. Does this modification help when selecting items from the menu?

4. The current menu design displays general heading, altitude and velocity values that are interpreted by the automation to generate the appropriate message for uplink (e.g. "climb and maintain" when the aircraft's altitude is lower than that shown in the display). Does this change improve the flexibility and usability of the menu?

5. Is the procedure used for controlling the turn direction (L or R) in a heading menu text uplink acceptable?

6. The MT list can now be suppressed and moved independently from the TI list. Is this feature useful? Why or why not?

7. It is now possible to suppress individual items on the MT list. Is this feature useful? Why or why not?

8. What should be done to improve the design of the Menu Text
   service?  Include any changes suggested by your
   answers to questions 2. - 6. above.

_____    THE CURRENT IMPLEMENTATION IS ACCEPTABLE -- NO
           CHANGES ARE DESIRABLE OR NEEDED

_____    THE CURRENT IMPLEMENTATION IS ACCEPTABLE -- NO
           CHANGES ARE NEEDED, BUT THE FOLLOWING WOULD BE
           DESIRABLE: (describe)

_____    THE CURRENT IMPLEMENTATION IS UNACCEPTABLE --
           THE FOLLOWING CHANGES MUST BE MADE:

# GENERAL DESIGN OF MENU LISTS

Over the course of the effort to design terminal Data Link ATC services, several modifications have been made to the TI and MT lists which permit the controller to minimize keyboard entries by selecting messages from menus. However, a number issues regarding the design and application of these menu lists remain unresolved. The intent of the following questions is to solicit your inputs on 1) the operational requirements for the menu used to send control clearances (MT) and 2) design features needed to minimize errors and maximize the controller's ability to use the menus effectively.

## STRUCTURED vs. FREE TEXT MENU ITEMS

The current design of the MT list is one example of a structured menu. Menu lines are assigned to specific clearance types and the content is highly standardized. The main advantages of this approach to menu design are that it allows extensive use of automation to construct the uplinked message, and that it offers much more compact and efficient coding of the clearance for transmission over the Data Link than if the message were sent as free text. The limitation of a structured system is that it may be too inflexible to represent all messages that a controller might want to send.

Conversely, the free text approach (like that adopted for the TI list) provides high flexibility in the menu, but is an inefficient way to send all messages over the Data Link.

Thus far, the terminal design for MT has progressively added several design features under a structured approach which are intended to increase the flexibility of the menu:

- Menu lines dedicated to speed, heading and altitude clearances which can be modified by the controller

- Capability to combine individual speed, heading, and altitude menu lines in a single uplink

- Capability to create a special multiple clearance item (Line 9)

- The menu by-pass feature for composing clearances in shorthand form in real time

- Generic clearance messages with automatic determination of climb/descend and increase/decrease, plus the ability to control turn direction

- Capability to combine a TI item with an MT item in a single message

Do you feel that the current Menu Text design with these options will be sufficient for generating the control clearance messages that will be sent via Data Link in the operational terminal environment?

_____ Yes, the current design is sufficiently flexible

_____ No, the entire menu must be changed to the free text format to provide sufficient flexibility

_____ No, the structured menu should be maintained, but one or more optional free text menu items must be added

_____ No, the following additions / changes must be made to make the system sufficiently flexible:

Regardless of your answer, please add any comments that you may have regarding the design of the MT menu:

FEATURES RELATED TO CONTROLLER PERFORMANCE AND ERROR

In addition to the issue of menu structuring, several features of
the design for the menu lists have been added to minimize
controller keyboard entry errors and to simplify the task of
searching for and selecting menu items.

**Rate each of the design features shown below in terms of the
extent to which you feel it will enhance or impair controller
performance when using the menus.** Place an "x" on the line to
indicate your rating:

1. The TI list and MT list are distinguished by their
   applications. The TI menu may contain only informational
   messages, while the MT list is reserved for control
   clearances.

```
+3        +2        +1         0        -1        -2        -3
 I_____I_____I_____I_____I_____I_____I
```

```
  Very                    No Effect                  Very
Positive                 On Errors Or             Negative
 Effect                  Performance                Effect
```

2. To reduce inadvertent selection of items from the unintended
   list, letters are used as item identifiers for TI messages and
   numbers are used as item identifiers for MT messages.

```
+3        +2        +1         0        -1        -2        -3
 I_____I_____I_____I_____I_____I_____I
```

```
  Very                    No Effect                  Very
Positive                 On Errors Or             Negative
 Effect                  Performance                Effect
```

3. Headers (or Spaces) are used to help in locating the desired
   category of clearances in a group of messages contained on the
   MT list.

```
+3        +2        +1         0        -1        -2        -3
 I_____I_____I_____I_____I_____I_____I
```

```
  Very                    No Effect                  Very
Positive                 On Errors Or             Negative
 Effect                  Performance                Effect
```

4. Unused TI items and MT items can be individually suppressed to reduce list length and clutter.

```
  +3        +2        +1         0        -1        -2        -3
   I_____I_____I_____I_____I_____I_____I
```

| Very | No Effect | Very |
| Positive | On Errors Or | Negative |
| Effect | Performance | Effect |

5. The entire TI list and/or MT list can be suppressed to reduce clutter.

```
  +3        +2        +1         0        -1        -2        ··3
   I_____I_____I_____I_____I_____I_____I
```

| Very | No Effect | Very |
| Positive | On Errors Or | Negative |
| Effect | Performance | Effect |

6. The TI list and MT list are independently movable to minimize visual scanning requirements.

```
  +3        +2        +1         0        -1        -2        -3
   I_____I_____I_____I_____I_____I_____I
```

| Very | No Effect | Very |
| Positive | On Errors Or | Negative |
| Effect | Performance | Effect |

7. The key entries used to prefix MT clearances (H, A, V) are in a single column on the ARTS keyboard and in the same spatial order as displayed in the menu to simplify menu item selection.

```
  +3        +2        +1         0        -1        -2        -3
   I_____I_____I_____I_____I_____I_____I
```

| Very | No Effect | Very |
| Positive | On Errors Or | Negative |
| Effect | Performance | Effect |

**Please use the next page to add any other features that you feel may enhance controller performance when using the menus**

# APPENDIX C

## STRATEGY ASSESSMENT MATERIALS

Arrival/Final
Test Run Questionnaire

## DATA LINK - 2 CONTROLLERS

Run _____

Controller _____

Assistant _____

-- **Please complete this questionnaire as a team. If you do not agree on an answer, record both views.**

1. Briefly describe the sequence of clearances that you used to control the traffic presented in this scenario. Include any strategies that you may have developed to efficiently move the arriving aircraft onto the final approach. (If this is not your first test run under "Data Link with two controllers", describe only those changes that you made since your last experience)

2) How did you divide your duties during the test run?

Controller Duties:

Assistant Duties:

3) Did your approach involve sharing of radio communication duties? If so, what communications were handled by the each controller?

4) Did your approach involve sharing of Data Link communication duties? If so, what communications were handled by each controller?

5. Describe any modifications that you made in your approach to controlling the aircraft as the traffic level increased during the test run.

6. What messages did you send using Data Link? Describe any situations where you were unable to use Data Link for those messages.

7. Describe any changes to the TI list that you made for this test run. (e.g. change default, modify message content, reposition list, suppress items).

8. Were there any situations where you were unable to use the Data Link to send TI messages? (describe)

9. Describe any changes that you made to the MT list for this test run (e.g. change values, reposition list, suppress items)

10. What MT clearances did you use during the test run? Did you use the menu bypass function? (describe).

## 11. CONFLICT RECORD

A conflict is defined as a loss of IFR separation. Please note
the ID's of conflicting aircraft and complete this page after the
test run. Under "cause of conflict" please note whether the
conflict was a result of pilot error, related to the use of Data
Link, or some other problem.

ACID 1      ACID 2        Cause of Conflict

_____     _____       _____

            _____

            _____

_____     _____       _____

            _____

            _____

_____     _____       _____

            _____

            _____

_____     _____       _____

            _____

            _____

_____     _____       _____

            _____

            _____

_____     _____       _____

            _____

            _____

ARRIVAL/FINAL CONTROLLER POST-TEST QUESTIONNAIRE

Controller Name: _____

In the following three questions you will be asked to make all
possible comparisons of the four combinations of controller team
size and communication condition that were used in the Test Bed
simulation trials.  One of the possible pairs is presented on the
left and right of each line.  Place an "X" in the space which
best describes your view of which of the two combinations was
higher on the factor being addressed (Individual Workload,
Capacity, or Safety).   If the pair did not differ on that
factor, place the "X" in the "Equal" space.

The following abbreviations are used to specify the four
combinations:

     1C/V - 1 Controller, Voice-Only Communications

     2C/V - 2 Controllers, Voice Only Communications

  1C/V&D - 1 Controller, Voice and Data Link Communications

  2C/V&D - 2 Controllers, Voice and Data Link Communications

1) Compare each of the following pairs of controller and
communication conditions on the basis of INDIVIDUAL CONTROLLER
WORKLOAD.

| | <--Higher Workload | | | Higher Workload--> | | |
|---|---|---|---|---|---|---|
| | Much Higher | Somewhat Higher | Equal | Somewhat Higher | Much Higher | |
| 1C/V | _____ | _____ | _____ | _____ | _____ | 2C/V |
| 1C/V | _____ | _____ | _____ | _____ | _____ | 1C/V&D |
| 1C/V | _____ | _____ | _____ | _____ | _____ | 2C/V&D |
| 2C/V | _____ | _____ | _____ | _____ | _____ | 1C/V&D |
| 2C/V | _____ | _____ | _____ | _____ | _____ | 2C/V&D |
| 1C/V&D | _____ | _____ | _____ | _____ | _____ | 2C/V&D |

2) Compare each of the following pairs of controller and communication conditions in terms of their IMPACT ON SYSTEM CAPACITY.

| | <--Higher Capacity | | | Higher Capacity--> | | |
| | Much Higher | Somewhat Higher | Equal | Somewhat Higher | Much Higher | |
|---|---|---|---|---|---|---|
| 1C/V | _____ | _____ | _____ | _____ | _____ | 2C/V |
| 1C/V | _____ | _____ | _____ | _____ | _____ | 1C/V&D |
| 1C/V | _____ | _____ | _____ | _____ | _____ | 2C/V&D |
| 2C/V | _____ | _____ | _____ | _____ | _____ | 1C/V&D |
| 2C/V | _____ | _____ | _____ | _____ | _____ | 2C/V&D |
| 1C/V&D | _____ | _____ | _____ | _____ | _____ | 2C/V&D |

3) Compare each of the following pairs of controller and communication conditions in terms of their IMPACT ON SYSTEM SAFETY.

| | <--Higher Safety | | | Higher Safety--> | | |
| | Much Higher | Somewhat Higher | Equal | Somewhat Higher | Much Higher | |
|---|---|---|---|---|---|---|
| 1C/V | _____ | _____ | _____ | _____ | _____ | 2C/V |
| 1C/V | _____ | _____ | _____ | _____ | _____ | 1C/V&D |
| 1C/V | _____ | _____ | _____ | _____ | _____ | 2C/V&D |
| 2C/V | _____ | _____ | _____ | _____ | _____ | 1C/V&D |
| 2C/V | _____ | _____ | _____ | _____ | _____ | 2C/V&D |
| 1C/V&D | _____ | _____ | _____ | _____ | _____ | 2C/V&D |

**STRATEGY INTERVIEWS**

<u>Instructions to Facilitators</u>

The purpose of the strategy interview is to ask the controller to compare Data Link and voice after he or she have had a chance to use both systems during the twelve data collection runs. The interviews will consist of two parts.

First, a series of questions will be asked. Second, the controllers will be prompted to provide examples of incidents where they chose between using Data Link or voice. This second set of questions will specifically focus on the six Data Link runs when controllers had a choice over communication method.

Please take notes on the replies. If you need more room, please continue on the back of the page, noting the question number.


Controller Name: _____


Facilitator Name: _____

## Part One Questions

1. What were the differences in your team strategies (with two controllers working arrival/final) between voice only and Data Link with voice runs?

2. In which communication condition (voice only or Data Link with voice) were the team strategies more effective and why?

3. What were the differences in your individual strategies (with one person working arrival/final) between voice only and Data Link with voice runs?

4. In which communication condition were your individual strategies most effective and why?

5. What do you think would be most desirable in a Data Link environment, sharing control of a combined sector or working separate arrival/final sectors?   Why?

6. Please indicate which communication mode you used to send ATC information and instructions in the following situations and why you used it:

a) Communication of Terminal Information message (arrival sector)

b) Altitude assignment

c) Heading change

d) Speed change

e) Conflict resolution (rectifying a loss of separation)

f) Dealing with missed approaches

7. Did Data Link delay time affect your use of Data Link in the individual or team control runs?

## Part Two Questions

This type of questioning focuses on "critical incidents" which occurred during the simulation runs. A critical incident is defined as a challenging event which went beyond the routine and required that the controller apply skilled ATC interventions.

Try to review at least two critical incidents from the preceding six Data Link with voice runs (where there was a choice over communication method). Please go through the steps on the following pages when collecting information on critical incidents.

**Critical Incident 1**

a) Select Critical Incident

Ask the controller to suggest an incident from the Data Link
runs (where there was a choice over using Data Link or voice)
which posed a challenging ATC problem.  (Please note in which
run the incident occurred.)

b) Obtain Incident Report

Ask for a brief description of the incident noting antecedent
conditions, information available, and actions taken
(including decisions to use Data Link or voice).

c) Construct Incident Timeline

On a horizontal timeline, note the sequence of events of the incident.

_____

d) Probe Decision Points

Identify on the timeline where decisions were made about the use of Data Link versus voice communication.  Ask specific questions to determine why Data Link or voice was chosen.

## Critical Incident 2

a) Select Critical Incident

Ask the controller to suggest an incident from the Data Link runs (where there was a choice over using Data Link or voice) which posed a challenging ATC problem.  (Please note in which run the incident occurred.)

b) Obtain Incident Report

Ask for a brief description of the incident noting antecedent conditions, information available, and actions taken (including decisions to use Data Link or voice).

c) Construct Incident Timeline

On a horizontal timeline, note the sequence of events of the incident.

---

d) Probe Decision Points

Identify on the timeline where decisions were made about the use of Data Link versus voice communication.  Ask specific questions to determine why Data Link or voice was chosen.

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